AIDING DECISION MAKING FOR FOODBANK CAPE TOWN

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Abstract

Foodbanking in South Africa began in March 2009 with the launch of FoodBank Cape Town (FBCT), an NGO that redistributes excess food from suppliers to agencies (organizations with feeding programmes). This dissertation assisted with the planning and research undertaken to help launch FBCT. Three key areas were tackled:

- Problem structuring techniques were employed to help structure the Cape Town FoodBank Forum (CTFBF), which was formed to launch FBCT, and to establish leadership for it. Project management techniques were also employed to guide the tasks required to establish FBCT.

- Assistance was provided for warehouse selection, where food would be brought from suppliers to be sorted, cleaned and stored before being distributed to agencies. Two areas were tackled within warehouse selection: optimal warehouse size and optimal warehouse location. Optimal warehouse size was determined by modelling inflows, outflows, the resultant nett food in the warehouse and the relationship between food stocks and the warehouse size required. Optimal warehouse location was calculated by modelling the cost of total truck-route trips to agencies and suppliers for a given warehouse location. By varying the warehouse location over a matrix of coordinates, the lowest cost for location could be found.

- An allocation model was formulated that will assist with deciding which agencies to give food to and how much, given the vast number of applications.

A clear structure was achieved by constructing working groups (for different areas of work required) with the CTFBF, the chairs of which formed the co-chairs and therefore leadership for the CTFBF. A warehouse of size 9501112 and 13701112 was recommended for the short and long-term respectively. An ideal warehouse location "zone" was generated whereby travel costs would be within 5% the optimal location, which roughly constitutes the interior of the polygon formed by the N2 and 1\17 (see Figure 5.1 on page 110). A warehouse was then selected at the Philippi Fresh Produce market, which performed very well with regard to the warehouse size and location criteria, as well as other important criteria. The research and pending practical application of the allocation model have been accepted by FBCT. The model is currently going through a trial phase, after which it will become operational for aiding FBCT's decisions 011 food allocation.

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- Most importantly, God, for giving me the opportunity and ability to do my MSc.

Plagiarism Declaration

1. I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.
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Signed. ....

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Nomenclature

Agency. An organization/NGO that receives food from the foodbank and uses it for feeding programmes, such as a soup kitchen or crche.

Beneficiary. A person who would receive food from an agency.

CTFBF. Cape Town Food Bank Forum, who were formed to establish FoodBank Cape Town.

Cut-off values. (see Chapter 4) A cut-off of 10% would refer to a certain amount of storage space which is passed **10%** of the time.

DC. Distribution centre of a supermarket chain.

End-level criterion. (see Chapter 6) A criterion with no sub-criteria under it.

FBCT. FoodBank Cape Town.

Feedback. One of the three merging organizations which formed FBCT (see also Lions and Robin Good).

GFN. Global Foodbanking Network.

Lions. One of the three merging organizations which formed FBCT (see also Feedback and Robin Good).

Main place. A geographical division of South Africa, defined by StatsSA.

MCDA. Multi Criteria Decision Analysis.

Merging organizations. A term often used to describe Lions, The Robin Good Initiative and Feedback, as these three organizations merged to initially form FBCT.

MLL. Minimum Living Level, as defined by the Bureau for Market Research. This states the minimum amount of rand required for a household to live above the poverty line.

OR. Operational research.

Outflow factor. (see Chapter 4) A constant multiplied by the weekly average non-perishable inflow to the foodbank, in order to determine the outflow aimed for by FBCT during the week (see section 4.4.2).

Recovery rate of food types. When the foodbank receives product some is fit for human consumption and some is not. The recovery rate denotes the proportion that is not.

Region. (see Chapter 5) A geographical area used to group suppliers and agencies together.

Region trip. (see Chapter 5) A trip where the truck delivers all of its product to one region before returning to the warehouse.

Robin Good. One of the three merging organizations which formed FBCT (see also Lions and Feedback).

Scenario. A certain state under a criterion.

SI. Systems Intelligence.

Situation. A set of scenarios for different criteria.

SODA. Strategic Options Development and Analysis.

SSM. Soft Systems Methodology.

Chapter 1

Introduction

FoodBank Cape Town (FBCT) opened its doors on 2 March 2009. In so doilig, it became the largest foodbank in Africa, providing the equivalent of roughly 12 million meals annually to underprivileged individuals, though this figure is expected to grow rapidly. This was the first of a series of four such foodbanks to he opened in the then near future in South Africa, all to be joined together by the national network, FoodBank South Africa (FBSA). This mini-dissertation was aimed at aiding the decision-making for FBCT up until its opening and spans social issues and management, systems modelling, project management, logistics and resource allocation. rrhis chapter outlines what foodbanking is all about, describes how it fits into the South African context and its applicability to the local environment.

1.1 Description of Foodbanking

A brief history of the origins of foodbanking is given (this information was taken from three organizations' websites: [Global Foodbanking Network], [America's Second Harvest] and [St. Mary's Food Bank Alliance]), followed by a description of how it works and why it works from an Operational Research (OR) perspective.

1.1.1 A brief history

John van liengel has been recognized as the "Father of Foodbanking". In 1965, he started volunteering at a local soup kitchen at St. Vincent de Paul in Arizona, Phoenix, US. He soon realized that perfectly good food was being disposed of by grocery stores. The reasons for disposal would normally be minor defects in packaging or food being near expiration date. He then convinced store managers to donate this food to St. Vincent de Paul. This initiative quickly grew, and in 1967 van Hengel approached St. Mary's Basilica, and with their help, started the first "foodbank"

The first year of operation was a great success — more than 110 tons of food was distributed to 36 local agencies (organizations/NGOs that have feeding programmes). The idea quickly grew to other cities and van Hengel then acted as a consultant to many of them. In 1976, van Hengel left the St. Mary's foodbank to start Second Harvest (later called America's Second Harvest), an organization that both forms a national network of foodbanks and aids others in establishing new foodbanks in the US.

In the 1980's, van Hengel left Second Harvest to assist other countries in starting foodbanks, which led to the development of the International Foodbanking Services Inc. This organization acted as a consulting firm to aid foodbanks worldwide. In 2005 Johan van Ilengel passed away. Inspired by his example, the Global Foodbanking Network (GFN) was established in 2006. GFN's mission is to "work collaboratively to alleviate world hunger by developing national networks of foodbanks and strengthening foodbanking around the world" [Global Foodbanking Networks]. It does this by helping foodbanks that already exist in countries outside the US, and by working to create new ones where they are needed.

As of January 2009, America's Second Harvest distributes more than 900,000 tons of donated food and grocery product annually to more than 25 million hungry people in the United States, while GFN currently operates in 14 countries.

1.1.2 FoodBank Operations

Foodbanks are non-profit organizations that aid the community by distributing unused food to agencies that feed the hungry. A typical foodbank, part of America's Second Harvest, would operate as follows.

1. Finances, and food that would otherwise go to waste, are donated by individuals and companies to the foodbank. Reasons for food donations include labelling errors, food near expiration date, brand discontinuation, inventory surplus, minor recipe variation, damaged packaging, etc. Small volumes of food (at most 20% of the total volume) are also bought to supplement donations.

2. The foodbank collects food from various locations using trucks and brings it back to its warehouse.

3. The food is sorted, cleaned, etc. and put on shelf.

4. Agencies, which would use this food for social upliftment, can walk through the "shopping section" of the warehouse (where items are put On shelf) and can select what they need at little or no cost (a small handling fee is sometimes changed). In addition, food may also be delivered to agencies.

5. Agencies then supply this food to the hungry through various programmes. These agencies/programmes include school feeding programmes, soup kitchens, abuse clinics, etc.

During this whole process, quality control standards are ensured.

GFN places a strong emphasis on foodbanks being community assets. Although it may be managed by an NGO, the local community must take ownership of it be actively involved in its establishment and running in order for it to be successful. Because of this, foodbanking also has an impact on the public awareness of hunger and its solutions, as well as affecting public policy decision-making. GFN is also aware that in most cases foodbanking on its Own will not solve the problem of poverty. Social development problems are often very complex and many factors need to be considered and addressed by the actual community. However, foodbanking has proven to work successfully by "bringing together the public sector (government at all levels), the private sector (the business community — including the food industry and the media), and the voluntary sector (the NGO community) in serious dialogue and action aimed at addressing the needs of hungry people" [Global Foodbanking Network].

1.2 Foodbanking in South Africa

The origins of foodbanking in South Africa are first discussed, after which the applicability of foodbanking to South Africa is critiqued.

1.2.1 GFN's Presence in South Africa

As stated earlier, GFN's main objective is to aid other countries in establishing foodbanks in their own countries. With the support of South African organizations, GFN completed a "proof of concept study" and "feasibility study" during 2007. These studies looked at the nature of the hunger problem, assessed potential resources for a foodbank network and built community and national coalitions and partnerships. The results of these investigations were positive and it was decided that, during 2008, a national plan and a design for South African foodbanking would be developed, which would then lead to the actual setting up of foodbanks. With the help of key stakeholders in South Africa, GFN established national and community forums, which would be used to tackle the work required for 2008.

The national project was led by the South African Forum for Food Security (national forum), which as of 15 January 2008, consisted of 38 organizations. Community forums were established in Cape Town, Johannesburg, Durban and Port Elizabeth. The national forum would focus more on the "broader" issues and policy decisions, while the community forums would focus more on "on the ground" work and the details of actual implementation. Ideally, each city would develop its own unique style of foodbank suitable to its environment but there would be similarities/guidelines between foodbanks on a national level.

1.2.2 The Applicability of Foodbanking to South Africa

It was once argued that in order to solve the problem of under-development, developing countries simply needed to adopt the "already existing

"had no need to repeat the long and troublesome path" through which the developed countries had previously come [Ravi' et al., 1986]. Over time, however, this transfer ideology was seriously criticized and in practice fell short in many ways. This was largely due to the different socio-economic environments and hence an under-appreciation for t he different systems (particularly social) in which they operate. It is therefore important to consider if foodbanking is applicable to the South African environment (i.e. transferring foodbanking from a developed country to a developing country), and if so, how it might differ in its application. Not, much time is spent answering the former question, as although it is essential, this dissertation is more concerned with the latter.

With regard to foodbanking's applicability to South Africa, GFN's record of accomplishment of having already established many foodbank networks in developing countries probably speaks the loudest. In fact, the concept of foodbanking is fairly intuitive and as a result many similar smaller initiatives had already been running successfully in South Africa for many years before

GFN or foodbanking was ever heard about. The reason it is applicable in almost all environments is most likely because it is a fairly simple concept -- all countries dump very large quantities of good food while there are many hungry people, and the cost of getting this food to the hungry people is almost negligible in comparison to the cost of the food itself. This goes for all countries, developing or not. Importantly, foodbanks do not try to solve poverty (this is a much deeper issue embedded in a complex social system); they simply address the issues of hunger by distributing excess food.

With regard to its application, the nature and size of the foodbank will vary depending on a number of factors. However, because local community participation is seen as critical by GFN, solutions are tailored to local environments so that the needs of the community are met. Nevertheless it is useful to consider how the US and South African environments may differ and how this could impact on how foodbanks in these regions might differ, as this will inevitably influence any OR studies undertaken. This was particularly vital in the present case as the representatives from GFN offering expertise in foodbanking obtained their experience in the US.

The socio-economic structure in the US is one where food expenditure is much higher per capita than in South Africa. The amount of waste (and hence food for the foodbank) generated in the US per capita will therefore be higher than in South Africa. Coupled with this is a larger proportion of the population living in poverty in South Africa. As a result, South Africa would have smaller amounts of "waste" to serve more people in need in comparison to the US. Foodbanks in the US have big warehouses stocked with large amounts of food with "shopping" areas for NGOs to select which food items they need. In South Africa, the number of hungry people will almost certainly always out-weigh the available supply of food. A "shopping" set-up for NGOs would therefore not work. There would also probably not be a need for large warehouses as whatever food collies in could immediately be used by someone.

In addition, the US is very market driven, which has resulted in a system of trading (much in the same way as a stock market) between individual foodbanks. For example, one foodbank may have excess apples and so put these on the foodbank -market", while another may have excess bananas and so these are also put on the "market". Different foodbanks can then ascertain what is On the market while supply and demand can determine -prices" (in this case it is not money traded but some other nominal form of currency). South Africa is not as market orientated as the US and does not have the same online capabilities, therefore this trading system would probably not work as well and an alternate solution may be better suited.

Chapter 2

Problem Description and Background

The Cape Town foodbank Forum (CTFBF) essentially became the client for research, where research was aimed at helping to aid decision making for FBCT. The research undertaken broadly fitted into 3 categories.

1. Problem structuring techniques (interviews and causal mapping) and project management techniques (critical path management) were used to aid the forum in establishing FBCT ((Chapter 3)).

2. One of the critical tasks identified in establishing a foodbank (from the critical path analysis) was that of selecting a suitable warehouse, however there was no clear indication as to what size would be required or where the facility should be located. Research was therefore conducted into both of these issues (Chapters 4 and 5).

3. Finally, the specific problem of allocation was investigated (Chapter 6), which deals with how FBCT decides which organizations to distribute food to and what amount to each.

In the following sections these problems are discussed in more detail with reference to relevant literature.

2.1 Aiding the Cape Town Foodbank Forum to Establish FBCT

The background to the problem and description of it are first given, after which relevant literature is explored.

2.1.1 Problem Background and Description

The Cape Town forum (formed to ultimately establish a foodbank in Cape Town) held monthly meetings from (January 2008 onwards and constituted a wide range of stakeholders due to the early work done by GFN. The forum consisted of a total of about 30 people. Actual attendance usually ranged from 15 to 20, however the key role-players remained fairly constant through 2008. The forum could be divided into roughly four categories.

1. *GFN representatives,* who had many years of experience working with foodbanks in the US. They were there to initially help guide the process and offer expertise/help wherever necessary; however, in the long-term, their goal was to act more in an advisory capacity and for local people to drive/lead the process.

2. *NGOs who were already doing foodbank type work (re-distributing food to agencies).* These NGOs included Feedback, The Robin Good Initiative and Lions.

3. *Suppliers.* One person, on behalf of a major retailer, was the only supplier representation.

4. *Agencies.* There were a number of NGOs who were involved with feeding programmes that would be able to make use of potential food.

As time progressed, the three NGOs who were seen to have previous experience with foodbanking related work seemed to carry a large amount of weight/power within the group and seemed to be driving the process, as well as doing most of the work. In fact these three organizations, along with the GFN representatives, constituted the "Cape Town working committee". This group was originally set up to discuss how these three organizations could merge to form FBCT. However, at these meetings it became clear that in order to do this, an understanding of how the foodbank would operate was needed. Hence, the working committee pushed forward, tackling issues around how the foodbank would be structured and the processes to be followed.

Quite soon there were feelings of discontent expressed within the Cape Town forum around the fact that the working committee was doing work that was originally to be addressed by the forum. It was therefore decided that the working committee would be terminated. At this point the forum lacked structure and direction and, as a result of the disembodiment of the -Cape Town working committee", there was no clear leadership. Individuals were committed and willing to work toward establishing a foodbank in Cape Town, however there was no guidance as to who should do what.

Consequently, the -problem" presented was in pulling everyone onto the same page and in the same direction and providing a structure for the forum with a clear indication of leadership; and from this for members to have a clear idea of their roles and responsibilities. It would also be beneficial for participants to have an increased understanding of what foodbanking is about. An act ion plan was finally required in order to establish the foodbank and provide an order of execution of tasks.

As OR is aimed at aiding decision-making an essential aspect of the research was making sure that decision-makers would be responsive to it. It was thus important to appreciate these "power dynamics" as essentially there was no sole decision-maker, but rather a group (the regional forum) who were collectively responsible for making decisions. In order to build inter-personal relationships with key decision-makers and understand the current set-up, all CTFBF and Cape Town working committee meetings were attended, as well as numerous others being initiated. The current operations of the NGOs doing foodbank type work were also studied (which included spending a working day with a Feedback truck driver) in order to better understand current operations.

2.1.2 Relevant Literature

There are a variety of methods that can be used for problem structuring that are of the "softer" nature. Some of these include soft systems methodology, a dialectical approach, cognitive mapping, strategic choice, systems thinking interactive planning.

Three case studies were reviewed, namely "Publish or Perish'? - A Case Study" [Eden and Jones, 1980], "Perish the Thought!" [Eden, 1985] and 'Achieving 'Desirable and Feasible' Change: An application of Soft Systems Nlethodology" [Checkland, 1985]. Each case study describes a consultancy project aimed at aiding participants to tackle complex problems in the business environment. The first two used cognitive mapping while the third case study made use of Soft Systems Methodology. An example of the type of problem encountered was the need to turn around an ailing journal ("Publish or Perish'? A Case Study" [Eden and Jones, 1980]. These case studies were seen to be relevant to the current problem with regard to helping participants to tackle complex ill-defined problems. The underlying principles vere therefore seen to be more important than the specific methods or problems themselves. These basic principles are now outlined.

In each case study, all members of the team were involved in developing visual maps and aids, which helped to better understand and structure the problem. The role of the OR analyst in these methods is that of a facilitator of the process. The main benefit is a better understanding by all participants. Differing views are shared and participants can learn from one another. The processes involved are very much iterative and jumps can be made to and from steps. Once the problem is well structured, proposing courses of action and evaluating their suspected performance seems much simpler and this can be carried out, after which an actual "action plan" can be developed. On-going future evaluation of the same manner then results in an adaptive system to a changing environment. By involving all members, practical implementation is also made easier as there is a stronger sense of ownership among participants.

2.2 Warehouse Selection

As previously stated a suitable warehouse needed to be selected. There were three main options to choose from, and a number of possible alternatives within them:

1. To lease an existing warehouse;

2. To buy an existing warehouse; and

3. To find a plot of land and build a warehouse.

Through forum meetings and input from experts in warehousing a number of criteria were determined for deciding which warehouse alternative would be most suitable. These included financial cost, office space, safety and security, size, location, facility condition, etc. It became evident that there was no real sense of what would constitute a good/bad warehouse size and location. GFN representatives recommended a warehouse of 25001112 — 50001112, though this was from experience in the US and therefore perhaps not directly applicable to the South African context. As warehouse size and location are fundamental to warehouse selection, the first part of this research was to determine what an "optimal" warehouse size and location would be and how available warehouses would compare with this. Due to the extent of the research into these issues, they are dealt with in separate chapters (chapters 4 and chapters 5), while the details of each problem are discussed separately in the subsequent sections.

In practice, a number of warehouses were evaluated while researching the size and location issues. In particular, a 12001112 warehouse was found for lease at the Philippi Fresh Produce Market, which was said by the experts in warehousing to perform very well on all criteria, though it was uncertain as to how it performed with regard to size and location. The second part of this research was thus to determine its performance in these areas, which it was found to perform very well in.

A potential research approach was envisioned for aiding the selection of a warehouse whereby key decision-makers would be taken through a Multi Criteria Decision Analysis (NICDA) process. However, as the Philippi warehouse performed so well with respect to all criteria, particularly when compared to the alternatives, it would probably have dominated the others. There was therefore no need for an explicit MCDA process.

The decision was therefore made to lease the Philippi warehouse option, although it then became evident that there was an option to lease half of the space rather than the full space. Although the full space was recommended for warehouse size, there were reasons (to be discussed later) for taking a short-term lease on the 600m2 option rather than the 1200m2 option. This resulted in a decision between two alternatives which formed the final part of the research on warehouse selection (which is covered in the chapter on warehouse size, as it is more pertinent to that study).

2.3 Warehouse Size

Very simply, the foodbank required a sense of what size warehouse would be adequate to handle inflows, particularly in the short-term (roughly 1 to 2 years), though also in the medium- and long-term (past 2 years). As it was planned that FBCT would start by merging Lions, Robin Good and Feedback (termed the -merging organizations"), the current inflows of these three organizations would form the inflows for FBCT's opening, though in addition there is expected to be significant early growth. Inherent in the warehouse size problem is an investigation into inflows, outflows and flow of product through the warehouse. By studying these areas a number of secondary objectives resulted:

- To calculate the required cold and frozen storage space;
- To conduct a data analysis on the historical inflows of the merging

organizations; and

• To determine policies for the management of dispatches.

It was envisioned that a simulation model would be created to capture the unique characteristics of the foodbank setting and to therefore model required warehouse size. Essential to this would be an understanding of stock rotation, which is inherent in inventory management. The most typical classification of inventory management problem is now discussed along with the available OR methods. It is then argued that these methods do not fit well within the foodbank problem setting. A more general approach to inventory management is therefore briefly reviewed and the relevant information to foodbanking is selected.

2.3.1 Traditional Literature on Inventory Management

The majority of literature and mathematical models for inventory management are focused on an industry context of businesses maximizing profit. Lee and Nahmias [1993] state that "Most mathematical inventory models are designed to address two fundamental issues: when should a replenishment order be placed, and how much should the order quantity be." (p. 3). This is within a typical problem setting of a business ordering raw materials, using these in production and delivering them to meet customer demand. A number of models are based on this type of problem amid variations occur depending upon the assumptions made and the level of complexity included. Demand is seen to be the major stochastic contributor to the problem and this can be included in the model with the additional "cost" of extra complexity. The foodbank setting contrasts quite strongly to the typical inventory management methodology in a number of areas:

1. *Stochastic supply and constant demand.* Whereas classical inventory problems assume deterministic supply and stochastic demand, this will be the opposite for the foodbank. Interestingly, for foodbanks in the US, demand may still be a stochastic contributor, though still to a far lesser extent than supply. This is due to the different environment compared to South Africa. In the US, food surpluses are larger and agencies are fewer, allowing greater freedom of choice in product for agencies. In South Africa, agencies have generally said that stability in food volumes is preferred over larger volumes with fluctuations. Therefore, as a rule of thumb, demand can be assumed deterministic.

2. *Decision variables.* Because of the different demand and supply structures, the decision variables will inevitably change. Where for classical inventory management the decisions are on order quantity and time, the decision variables for the foodbank are on how much food to give out and when. Therefore, even though stochastic supply could be included in the model as an extra complexity, the change in decision variable fundamentally changes the structure of the problem.

3. *Costs.* Inventory management cost is a critical part of classical inventory management. Economies of scale when buying in bulk is one of the main motivating factors for holding large inventories. Balancing this out are holding costs (warehouse space, taxes, insurance, etc.), which increase according to the amount of inventory held. In comparison, there is generally less of an emphasis on purchasing costs for the foodbank as food is donated. In addition, for the foodbank, costs are measured against social outcomes, such as helping the poor, rather than against profits.

As a result of this -misfit" in problem structure, the typical OR techniques for inventory management seem to not be applicable. Journal articles were scanned for similar problems to that of foodbanking but nothing relevant was found. Compounding this was the fact that "Most of the literature implicitly ignores the possibility of obsolescence or deterioration of stock" [Silver, 1981] (p. 633), which is integral to the foodbank set-up. In the few cases where literature is available for this, the focus is still on order quantities and times. Unfortunately hard OR techniques tend to be fairly rigid and inflexible to changes in problem structure, which meant that it would not have been realistic to attempt to adapt the available techniques to the foodbanking system. Nevertheless, some of the more general inventory literature and policies were reviewed for insight, and where applicable to the foodbank, this is stated in the next sub-section.

2.3.2 General Inventory Management

Vogt et al. [2005] and Grant et al. [2006] list a number of ways in which inventory management can be improved. Two of the most applicable areas to the foodbank are the reasons for holding inventory and forecasting, which will now be examined in more detail.

Reasons for holding inventory

The main reason for the foodbank holding inventory is to protect it against future uncertainty. This can be termed "safety stock", which acts as a buffer between supply and demand. The foodbank could simply deliver each day what it received, but this would create unstable and unpredictable supplies for agencies. The main reason for the foodbank to hold inventory is therefore to smooth out variability, so that more reliable, constant supplies of food can be given to agencies. According to Wild [2002], "The amount of safety stock held in an organization depends upon three main factors:

1. The variability of demand;
2. The reliability of supply; and
3. The dependability of transport" (p. 96)

For the foodbank's purposes, attention should be focused on the *variability* of supply (e.g. day-to-day variation, seasonal variation of particular food types, etc.). Incorporating demand variability in traditional examples, one would fit a Normal distribution to demand and set a safety stock according to the standard deviation and level of service required. For example, a service level of 95% (so that stock-outs would occur 5% of the time) would correspond to a safety stock of 1.64 multiplied by the standard deviation of demand. Application to the foodbank, however, would be different as traditional examples would have variable orders (supply) to meet variable demand, where the safety stock acts as a buffer. For the foodbank, one cannot vary demand to meet varying supply as demand is constant. Even the safety stock cannot be ordered but, in effect, must be created by hampering outflows (which in turn affects demand satisfaction). The foodbank system therefore appears more complex and intertwined than inventory management systems as inflows (supply) and outflows (demand) cannot be as easily separated by a safety buffer.

Forecasting

Demand forecasting is a critical part of inventory management for typical business, though for the foodbank supply forecasting could be critical. Types of forecasting that could prove useful to the foodbank include qualitative (subjective judgement), time series and causal methods (finding a cause-effect relationship). Time series methods were predominantly tested in this dissertation, though underlying qualitative causes were also sought. Wild

[2002] lists a number of reasons for forecasting demand inaccuracy. Those that apply to forecasting supply are listed below with their application to this dissertation.

1. *Inaccurate data or a shortage of data.* This was a large problem for the foodbank as data was only available from one of the three merging organizations.

2. *Sometimes sales statistics are reported instead of demand,* and the two do not always correspond (e.g. if items are out of stock). Applying this to supply for the foodbank, caution was used in using volumes given. It could be that "waste" from an organization is picked up once a week, which contains all the waste for the last seven days. Thus, a spike occurs once a week, when in actual fact there may he constant waste from day to day.

3. *Sometimes special events are included in forecasting data,* which can cause demand to spike that is not due to true demand variation. There also may be "constant customers" who order in every time-period. These cases should all be removed from the data and catered for separately when managing inventory. Variation will be much higher if these are taken into account, whereas in practice they can be anticipated and the -true variation" is much lower. This was not encountered in this dissertation, though could apply to potential future food donors that commit to giving a certain amount of food per time period.

2.4 Warehouse Location

The warehouse location problem is concerned with finding the location of the warehouse that minimizes transportation costs incurred by FBCT. In addition, there should be an indication of the magnitude of these costs and how they differ from one location to the next so that the difference in "value" between locations can be assessed, particularly with regard to the Philippi option. It was important to assess both current transportation costs as well as predicted future costs in order to minimize total costs over the long run (even if the warehouse was leased short-term it would be very costly to later move to a better location, therefore the location is viewed as fixed over the long-term).

The actual day-to-day transportation operations are quite complex, thus for the purposes of warehouse location it was simply assumed that a list of suppliers, that are collected from once per day, and a list of agencies, that are delivered to once per week, exist. Again, due to the research undertaken, a number of related areas were explored and as a result secondary objectives arose.

- The required number of trucks and drivers was explored as well as the size that the trucks should be.
- The number of deliveries per week to agencies can vary. The impact of this variation on overall cost was assessed.
- A pick-up radius was suggested whereby agencies within a certain radius of the foodbank would need to pick up food from the foodbank and the remainder would have the food delivered. The cost implication of this on the foodbank and agencies was explored.
- It was assumed that there would only be one central warehouse. Although a multi-warehouse set-up is possible, it would almost certainly be inefficient to spread the management function over geographical locations. A suggestion was however put forward to use depots for delivery. Essentially the foodbank would deliver food to depots, which would act as drop-off points. Agencies close to the depot would then collect food from a delegated nearby depot. This option was compared with delivering straight to agencies in order to determine which would be better.
- A basic routing algorithm was coded and used with the vision that this could later be extended for the actual daily routing of trucks.

A simulation approach was decided upon that would estimate total transportation cost for different warehouse locations. A simple and useful case study was then reviewed from Whiteman [19644 whose methodology is very similar to the one that was employed in tackling this problem, and shall be discussed in the next sub-section. In addition, literature was reviewed on vehicle routing in order to incorporate this into the simulation model. Although a routing algorithm was not completely necessary for the warehouse location problem, it was seen to increase accuracy and, more importantly, it could later be extended to assist with actual routing for the foodbank.

2.4.1 Liquor Distribution Case Study (Whiteman [1964a])

The case study involved a wholesale liquor distributor that wanted to build a new facility for distribution in 1961. Both single and multiple warehouse options were considered and the objective was to minimize overall cost. Costs applicable and dependent on the selection of warehouse sites were broken down into three categories: distribution costs, real estate costs and the increased processing costs incurred through using multiple warehouses over a single warehouse. In this study, distribution costs were found to be substantially larger than the other two costs. The following procedure was used to calculate the distribution cost of any given warehouse location:

1. Geographical centres of sales districts were estimated as well as the aerial distances between them;

2. A sample of road distances between points was calculated and compared with aerial distances in order to determine a scaling factor (found to be 1.3 in this case);

3. The number of truck trips required to each sales district was calculated by converting the annual sales for the district to cases of liquor and dividing it by the average truck capacity;

4. The cost of servicing a district was then the product of the number of trips per year, the length of trip and the average mileage cost of truck operation;

5. The total distribution cost was then the summation of servicing all regions except the one that contained the warehouse.

Using the above methodology a contour plot for distribution cost could be calculated as per the coordinates of the warehouse. A prediction for sales was also generated for 1970 (9 years later) and this was used to generate a second contour plot. The two contour plots (using present and expected future sales) were compared to assess the sensitivity of the warehouse location to future changes in sales.

In finding the optimal location for a single warehouse, an area of lowest distribution cost was found. Within this area, other aspects were then taken into consideration, such as real estate cost, zoning, etc. A number of possible options were put forward, from which the lowest overall cost could be calculated. In finding the optimal locations for the two-warehouse scenario, the sales districts were first split into two regions, each of which would be serviced by one of the warehouses. Each region could then be treated as for the single warehouse case with the addition of processing costs for having a two-warehouse set-up. Again, a number of possible options were listed and the total costs calculated, resulting in a number of single- and two-warehouse scenarios, each with a total cost. The choice then simply came down to selecting the option with lowest overall cost. Interestingly, a two-warehouse option seemed best (though largely through projected sales and thus future costs), where the second warehouse would act as a satellite of the main warehouse. However, the single warehouse option had its warehouse placed in a similar location to that of the main warehouse of the two-warehouse option. Thus, a phased approach was implemented, whereby the main warehouse was first built, after which sales for the subsequent few years could be measured and a decision on the possible satellite warehouse could be made.

2.4.2 Routing Algorithm

A routing algorithm was required to estimate logistical costs for a given warehouse location. In addition, the algorithm could later be extended outside the scope of this dissertation for actual routing. The goals of using a specific routing algorithm are first put forward. Broad literature on routing algorithms is then discussed and a specific algorithm selected, namely the Clarke and \Airight algorithm. A description of this algorithm is then given, which was taken from Fisher [1995], Battarra et al. [2007], Clark [1985] and Larson and Odoni [1981].

Aims in finding a specific routing heuristic

The important characteristics to consider when selecting an algorithm were:

1. *For it to be simple.* For the purposes of developing a warehouse location model, it would not make sense to spend excessive amounts of time on a vehicle routing algorithm.

2. [illegible]
expensive. A contour plot was envisioned whereby the cost of a range of different possible warehouse locations would need to be calculated in order to generate a three-dimensional graph of cost. In addition, proper sensitivity analysis would require running the model a large number of times over different scenarios. There would effectively be two routing algorithms to solve for each realization of the model (one for suppliers and one for agencies, each with a customer size of about 40), along with a number of other calculations to be made.

3. *For it to be adaptable.* It would be useful if the model could easily be

extended to incorporate additional complexities to form the basis of a, vehicle routing model at a later stage.

Literature on Routing

There is a substantial amount of literature on vehicle routing. One of the most popular and basic problem classifications is as follows: A number of customers need to be supplied by a central depot. These customers are supplied by a homogeneous fleet of vehicles (their capacity and fuel cost are equal) and the demand at each customer may vary. Let node set $AT = 0, 1,,$ where node 0 denotes the warehouse and nodes 1 to i
customers 1 to n. Cost matrix c is then defined such that cu is the cost of travel between nodes i and j. Cost matrix c is assumed known. The customers are served by a number of "truck-trips" which start and end at the depot and supply a number of customers on route. The objective is to minimize the cost involved in supplying all the customers.

This problem has been extended to take into account many other complexities (e.g. time constraints, stochastic elements, multiple depots, heterogeneous fleet of vehicles, etc.). Heuristics are generally used to solve these problems as the computational time involved for obtaining exact answers through optimization grows non-linearly with problem size. Three "generations" of vehicle routing research exist, as described by Fisher [1995]. These are:

1. Simple heuristics;
2. Mathematical based heuristics; and
3. Optimization algorithms and heuristic approaches based on recent results in artificial intelligence.

It was decided to use a simple heuristic as a result of its computational speed and simplicity (where simplicity is defined as the time required to programme the heuristic). Within simple heuristics, there exist three types [Fisher, 1995]:

1. Route building heuristics;
2. Route improvement heuristics; and
3. Two-phase methods.

Fisher [1995] lists a number of methods under these types of simple heuristics (p. 9), along with their performance and computational time (performance is defined as the minimum value for cost attained using the method). From these algorithms the Clarke and Wright method was chosen, which is the most well-known route building heuristic [Fisher, 1995]. It is simple and computationally very fast in comparison to the other algorithms. It is also very adaptable. The Clarke and Wright method has been modified to form other more complex algorithms, which either take into account extra complexities not considered in this application, or simply improve speed or performance [Fisher, 1995][Battarra et al., 2007]. The only downside is that it is the weakest method with regard to performance, however as the algorithm will only be used for the purposes of warehouse location this was not seen as a problem.

Description of the Clarke and Wright Routing Heuristic

The same set-up as that put forward in Section 2.4.2 is assumed (i.e. warehouse is node 0, customers are indexed by nodes 1 to *11,* cost matrix *c,* etc.). The Clarke and Wright algorithm then works as follows:

1. Start with each customer being supplied by a separate vehicle. This will result inn. trucks, each with its own route from the warehouse to a specific customer and back. By combining any two of these routes, one less vehicle is required and costs are reduced (as less distance is travelled). The cost for supplying customers i and j with two separate trucks is *co,* + c,0 *co.)* + cio, whereas the cost of supplying them using one vehicle and one route is *coi* + cij + cio. Therefore, the saving achieved by combining the two nodes into a single trip is the difference between the two: so = *c,0* co.) — *co.*

2. Calculate all so and rank them in descending order.

3. Starting with the highest so and, working down, merge the routes of customers i and j into a single route as long as the merge is feasible. A merge between customers i and j is feasible as long as the following three conditions are satisfied:

   (a) The capacity of the vehicle is not exceeded.

   (b) Neither i nor j can be internal in an already existing route. Customer i is internal if other customers are visited before *and* after visiting customer i. As an example, assume that a merge between customers 3 and 7 is proposed. Assume also that at the time of the proposed merge, custmners 3 and 7 are involved in the following two routes respectively: {0, 3, 0} (which denotes a truck starting at the warehouse, travelling to customer 3, then back to the warehouse) and {0, 1, 7, 2, 01. There are no customers visited before or after customer 3 (only the warehouse), thus customer 3 is not interior, whereas customer 7 is visited by customer 1 before and customer 2 after, and is thus interior. The merge is therefore infeasible.

(c) Customers i and j cannot be part of the same route. An example of this would be in trying to merge nodes 10 and 15 but with the following route already existing: {0, 2, 10, 5, 15, 0}. The reason this is infeasible is that if the merger did occur, a route would be created that does not start or finish at the warehouse.

4. The final set of routes will result after all the sij have been cycled through.

2.5 Food Allocation

As a starting point, it is assumed that there is a set of agencies that have applied for food support from the foodbank (as a policy the foodbank does not give to individuals). These agencies have certain food needs and the foodbank possesses a certain amount of food, both measured by weight. The foodbank must then select which agencies receive food and the quantity they receive each week. This section of the dissertation is concerned with developing a model that will aid in making these decisions.

The Equity model [Phillips and Bana e Costa, 2005] is often used in determining the optimal allocation of resources. The general idea for typical examples is fairly straightforward and will be explained using an investment portfolio context:

A range of possible investments is available. A Multi-Criteria Decision Making process is then undertaken to weight and score investments according to their associated costs and benefits, with adjustments for risk if necessary. Investments are then ranked from most efficient to least efficient according to the benefit-cost ratio. Cumulative costs are then plotted against cumulative benefits in order of the most efficient investment to the least efficient. From this the efficient frontier is generated (the investment portfolio that generates the most benefit for a given cost), which can be seen in Figure 2.1.

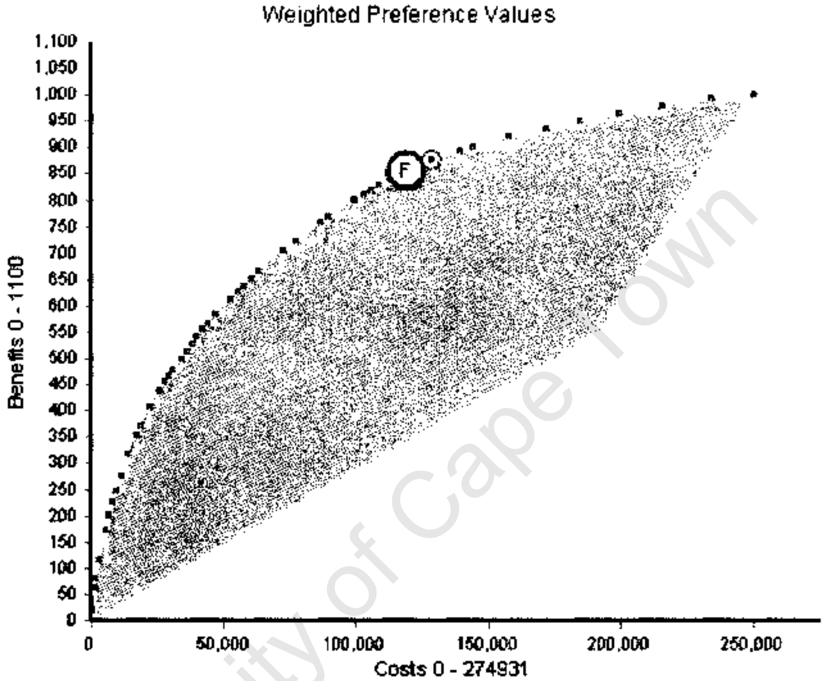


Figure 2.1: Example of an efficient frontier, displaying cumulative costs versus cumulative benefits [Phillips and Bana e Costa, 2005]

The foodbank example is, however, more complex and the problem slightly different. It is more complex in that there are two set of alternatives: where the investment example only has investments to consider, the foodbank has agencies and regions to consider. FBCT aims to distribute food to areas in proportion to the level of poverty in each area, where region needs are satisfied indirectly by supplying agencies which supply to these regions (see Chapter 6 for more detail). In addition, as more resources are given to an agency or region (i.e. investment) the marginal benefit alters and is non-linear (again, see Chapter 6 for more detail). In contrast, the marginal benefit for each potential investment is fixed for the Equity model up to a certain upper limit (in some cases, the option to invest is binary, though this can simply be seen as a special case of a linear relationship).

The problem also differs in the actual decision to be made. For the Equity model, an efficient frontier is generated and the decision maker must decide how much funding to use by looking at the associated overall benefit. In comparison, for the foodbank, the amount of food to be distributed will be dictated by how much is available therefore there will not need to be a decision on how much food to give. The problem for the foodbank is rather on determining the allocation that maximizes overall benefit, taking into account the agency and region needs as well as the altering marginal returns.

Due to the extra complexity and different problem structure, the traditional Equity model approach could not be fully utilized. MCDA was still used for weighting "benefits", which in this case were the components of the agency score (see Chapter 6). "Costs" in this case would be food volume and therefore one-dimensional, though a new approach was used for incorporating this into a model that would determine food allocation.

Due to the extra complexity and different problem structure, the traditional Equity model approach could not be fully utilized. MCDA was still used for weighting -costs" and -benefits", which in this case were food volume (one-dimensional) and the components of the agency score (see Chapter 6) respectively. However, a new approach was used for incorporating this into a model that would determine food allocation, rather than the efficient frontier approach.

Chapter 3

Aiding the Cape Town FoodBank Forum to Establish FBCT

This research did not follow a rigid methodology as outcomes of the early stages of research impacted on the methodology of subsequent stages of research. The first section of this chapter (3.1) therefore describes the methodology used while at the same time giving an overview of the research. Results from aspects of the research are noted as they are relevant to the methodologies of subsequent stages of research. The details of each component of the research are then given in the remaining sections (3.2 to 3.6). These components are:

- Stakeholder analysis and root definition formulation;
- Causal loop diagram analysis;
- Interviews with forum members;
- A workshop with the forum; and
- Project management.

3.1 Methodology and Overview of Research

The main problems identified were a lack of structure, understanding and direction within the forum (see Section 2.1). There was no leadership structure in place at the time, though this was considered essential. Sonic of the -softer" OR techniques were regarded as being ideal in order to bring people together onto the same page, to give a structured approach and to provide an action plan for moving forward. These included Soft Systems Methodology (SSM), Strategic Options Development and Analysis (SODA), which utilizes cognitive mapping as a modelling tool, Systems Dynamics and Systems Intelligence (SI) (though SI is more of an outlook than an actual methodology). No one methodology was implemented from beginning to finish. Rather, elements that were seen as being most beneficial were used from each of the above-mentioned methodologies.

The list below gives an overview of the research covered and will be discussed in more detail in the ensuing subsections:

I. Problem exploration and definition;

2. A workshop for the forum; and

3. Project management for long-term implementation.

3.1.1 Problem Exploration and Definition

Exploration Of the problem included four elements.

I. The various stakeholders were listed along with what they expected to achieve from the foodbank (this is akin to exploring and expressing the problem situation in SSM). In addition, an overall root definition was formulated for the foodbank (akin to the root definition in SS.M).

2. A causal loop diagram was drawn of the foodbank. This was akin to systems dynamics or SI. It is also similar to cognitive mapping in SODA, though different in that each person did not develop their own cognitive map.

3. Interviews were held with the major stakeholders represented in the forum (This is akin to SODA or SSNI, where interviews are conducted before the workshop to increase understanding and, in the case of SODA, develop individual cognitive maps).

4. In preparation for developing a Gantt chart, a preliminary list of tasks for the foodbank to become operational was constructed. This list was drawn up using a manual from Second Harvest', various meetings and discussions with members of the forum and personal brainstorming.

I Second Harvest is the name for the national foodbank network in the US. This manual was obtained frmn the GFN representatives.

After the problem exploration and definition it became dearer that the current problem setting differed slightly in comparison to what is usually dealt with by the softer OR methodologies. Typically, there would be a specific complex social problem within an organization or group of people that needs to be addressed. By constructing a systems model around this issue, the problem can be addressed holistically and from different people's perspectives. From this, actual root causes can be uncovered and courses for action then usually become self-evident. In comparison, the problem here was quite simple: the forum needed structure and direction as well as an increased understanding of foodbanking. Time constraints prevented an in-depth analysis of the problem - the forum only net once a month and it was therefore felt that at the following meeting a solution was required so that progress could be made. Two hours was allocated at the next forum meeting for a workshop in order to address this issue.

3.1.2 Workshop for the Forum

During the interviews, suggestions were made that the forum could split into different working groups which would focus on different aspects of the food-bank (e.g. logistics; supplier communications; etc.). Each working group would have a co-chair, and the co-chairs together would form a small executive group which would lead the forum. This group would then have the responsibility of meeting on a more regular basis to advance decision-making, though each co-chair's working group would be available to be delegated tasks. With regard to important decisions for FBCT, the smaller executive group could make recommendations though these would need to be referred to the larger group for approval. This ensures that everyone has a clear understanding of the structure of the forum, its leadership and how they can contribute. Since everyone is involved in the work and decision-making process, an inclusive process is achieved while work can be completed in an efficient manner through the delegation of roles and responsibilities.

As a positive response had been received from the key role-players in the forum with regard to this structural change, it was put before the full forum for feedback. The suggestion was well received. The process undertaken during the workshop was therefore, in essence, aimed at facilitating this change in a way that all participants felt involved and that they understood their role and how everything would fit together.

3.2 Listing the Stakeholders and Developing a Root Definition

A list of stakeholders in the CTFBF is given in Section 2.1, however a more detailed version is given below, including stakeholders not represented in the forum, with emphasis on what these various stakeholders hope to achieve from the foodbank. This was developed through many meetings and discussions with various individuals in the CTFBF and helped in defining the goals of the foodbank as well as uncovering potential "political" areas both within and outside the forum. It is also seen as important because emphasis is placed by GFN on the foodbank being a community asset; consequently, all facets of the community need to be involved and their personal goals for the foodbank need to be expressed. Below are the stakeholders and their goals.

- *Suppliers:* They want a foodbank they can trust to contribute to feeding the poor in an efficient and effective manner. 'They would also like good publicity/PR from the process.
- *The merging organisations:* They want to see the needs of the poor met and to contribute their expertise to this end. They also have concerns about their current organizations and whether the new set-up will be better for them.
- *NG0s:* They would mostly like a consistent, reliable volume of food over time, though the more food the better. They would also like to be able to have strong lines of communication with the foodbank to express their needs and concerns.
- *FBC7 staff:* They would like to be happy in their work, to be treated well and to serve the community.
- *Public:* They -would like to see the foodbank make a real difference to people's lives and for it to be handled efficiently and ethically. They would also like to see the root causes of poverty dealt with.
- *Underprivileged people:* They would like daily nutritious meals. They would also like to feel empowered to be successful and to not simply be handed food in a degrading manner.
- *Government:* They would like a well-functioning foodbank to reduce poverty. They would also like their public image to be enhanced through it.

A tentative root definition was then proposed as follows:

"A foodbank is a community asset that is trustworthy, well-run and complies with health and safety procedures. It assists suppliers in removing unwanted stock and provides NGOs with a reliable source of food that will help enable them to uplift and empower the community in a respectful manner."

Although this exercise was done without the forum members, it did shed useful light on the CTFBF and its stakeholders. A similar exercise was done in the workshop from scratch for the benefit of the individuals in the forum, though this exercise also helped in pre-empting answers from them.

3.3 Causal Mapping

A causal map of the foodbank was developed in order to better understand the system in which it operates and the factors that would contribute to its success or failure. The full model is given in Figure 3.6 in the appendix of this chapter, however a concise version is explained here, which highlights the more important aspects of the model (through discussions with CTFBF members the importance of different variables was gauged, which is not depicted in the causal map). With the directional arrows in the diagrams, positive relationships are implicitly assumed unless a (-) sign is used, which indicates a negative relationship. The central functions of the foodbank are given in **bold** writing in Figure 3.1.

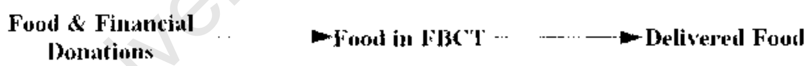


Figure 3.1: Simple causal map of the foodbank

In the case of FBCT, food will go to NGOs only and not directly to the end consumer, therefore "Delivered food" refers to food delivered to NG0s. The explanation of the concise model is now given, which is split into two parts. The first part starts with only a few of the variables and focuses predominantly on the flow of food through the system. 'The second part builds upon this mostly by incorporating the financial aspects missed out in the first part. Of particular importance will be the re-enforcing and balancing loops present, as these will dictate the behaviour of the system.

3.3.1 Explanation of Model: Part 1

The core of the model is given in Figure 3.2. There is one re-enforcing loop and one balancing loop, as well as the logistical infrastructure which influences the system. These loops and the logistical infrastructure will now be explained.

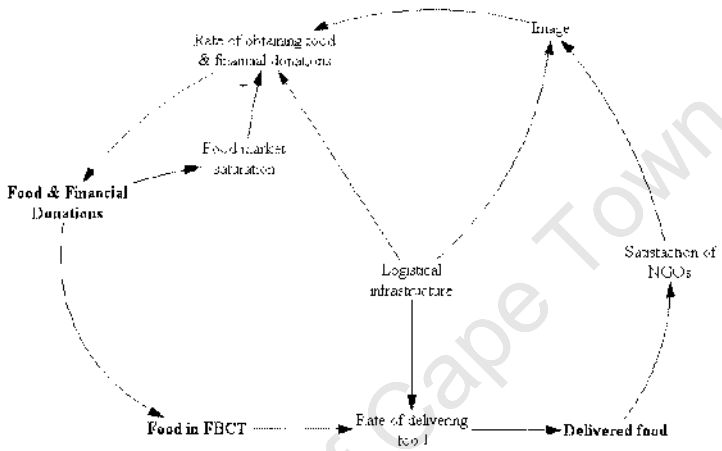


Figure 3.2: Core systems model of the foodbank

Loop: Satisfying NGOs

"Food and financial donations" indicates both the number of food donors as well as the size of their donations. Clearly, as donations increase more food enters the foodbank ("Food in FBCT"). Similarly, as more food enters the foodbank the "rate of delivering food" increases, which in turn increases the actual amount of food donated. Naturally, as more food is donated to NGOs their satisfaction increases ("Satisfaction of NGOs"), which in turn will generate good will about the foodbank, which will cause its public "image" to improve. Finally, an increased public image will result in an increase in the "rate of obtaining food and financial donations'. , which in turn will result in more "food and financial donations" .

Loop: Saturation of food market

As the system presented stands, there is nothing holding the foodbank back from growing exponentially ad infinitum. In reality the main constraint is a limit to the amount of "waste" in the food system. Clearly the number of food donors and the amount of food that can be obtained per food donor cannot increase indefinitely. Hence, in the model, as "food and financial donations" increase, so does the market for "waste food" become more saturated (-Food market saturation"). This in turn will cause a decrease in the rate at which donors are found ("Hate of obtaining food and financial donations"). This is the main balancing loop in the system which prevents the foodbank from growing indefinitely.

Logistical infrastructure

"Logistical infrastructure" refers to warehouse size, the number and size of trucks (including those of suppliers and NGOs that may occasionally be used), cold chain infrastruct ure, the efficient use of t hese resources, etc. As the trucking capacity of the foodbank increases, so does the "rate of obtaining donations". In addition, increases in the cold chain infrastructure of the foodbank will increase this rate if the foodbank is not able to ensure the correct quality and cold chain standards, food that requires these processes will not be donated by suppliers. Therefore, conversely, by having this infrastructure more food is able to be obtained. Similarly, as the "logistical infrastructure" of the foodbank increases, the rate at which food is donated to NGOs will increase ("Rate of donating food"). Note again that this would include the logistical infrastructure of agencies when they collect from the foodbank. Also, as the "logistical infrastructure" of the foodbank increases the public will be able to observe a more efficient and higher standard of operation, which in turn will increase the foodbank's -image".

3.3.2 Explanation of Model: Part 2

So far only food has been spoken about in the system. Figure 3.3 shows an extended view of the model, which incorporates financial aspects as well as a few other variables. The new variables (added to Figure 3.2) are now explained below.

- Importantly "funding" is now added, which refers to the amount of funds available for t he foodbank. Naturally as "food and financial donations" increase the amount of "funding" will also increase. An increase in funds will increase a number of other areas. These are listed below.

    1. The amount of "food bought" , which in turn increases the amount of "food in FBCT".

2. The "logistical infrastructure" .
3. The "overall management" of the foodbank. This essentially refers to managing the foodbank in its entirety as well as elements of it that are omitted from the model (e.g. financial management). It is assumed that as more funding becomes available for management this will improve, resulting in an enhanced -image".
4. -N1arketing" , which clearly improves "image".
5. "Accountability, record keeping, performance measures, etc." which was seen as important as donors wish to be ensured that their food is handled properly (quality control) and ends up in the right place (i.e. not sold on a secondary market), thus these measures are able to provide some peace of mind.
6. "Donor relations" . Funding is required to hire staff who can spend time sourcing food and raising funds. This in turn increases the number and size of donations.

Importantly, though these areas are increased by funding, the result will be an overall increase in the amount of financial and food donations. Note also that items (3) to (5) are influenced by other exogenous variables, such as personnel, though these are not displayed on the diagram.

- "BBBEE regulations". BBBEE regulations encourage corporate social investment (CSI). This "investment" includes food and money to NGOs such as the foodbank, therefore these regulations will impact the rate of donations to the foodbank.

- "Competition". FBCT will not be the only organization asking donors for financial and food donations. Essentially FBCT wishes to be the -middle man" between food donors and NGOs that have feeding programmes. However this does not stop other NGOs going directly to food suppliers with requests for food.

- -Economy" . As the economy worsens suppliers will generally try to save money by reducing their waste levels (this is evident in the current economic climate), hence recession in the economy will result in a decrease in the rate of donations.

- -NGO transport" . Food will not only be delivered to NG0s. Part of the logistical system will also involve NGOs collecting from the foodbank. Although this will increase the "logistical infrastructure" of the foodbank it will also decrease the level of -satisfaction of NGOs" . The same scenario will not play a major role on the supplier side and is therefore omitted.

All of the areas -funding" impacts on result in re-enforcing loops. Importantly, however, it is implicitly assumed that financial donations are restricted by the amount of food donations, as applications for funding are only substantiated by the promise of it resulting in more food for the system. This prevents the absurdity of the foodbank being able to place all their efforts into fund raising and then simply allowing these re-enforcing loops to grow exponentially. This extra complexity could be captured in the model, however as the model is only being used now as a visual guide it was decided to be left as is.

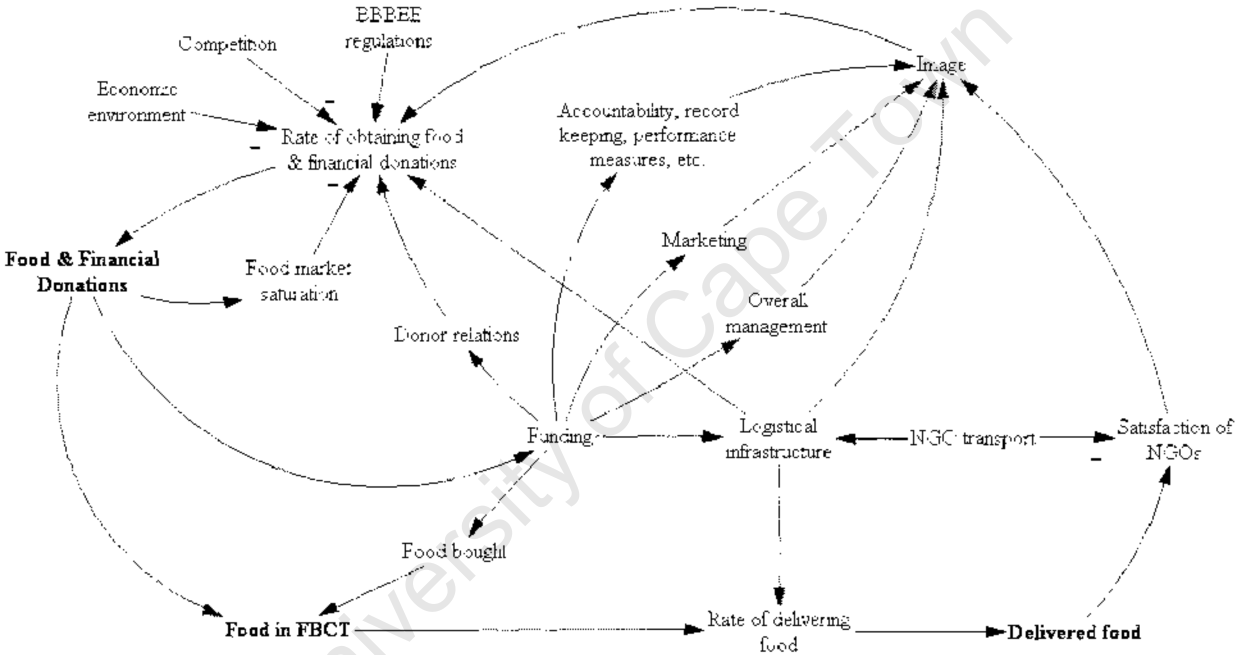


Figure 3.3: Core systems model of the foodbank extended

3.4 Interviews

Interviews were conducted to better understand the different perceptions that the forum members had on the foodbank and the actual problem, as well as to uncover any issues in preparation for the workshop. In addition, a few of the interviewees were shown a rough draft of the systems model in order to get feedback and to expose them to systems thinking before the workshop. Seven members were interviewed. These members included all stakeholder groups according to Section 2.1 except for GFN representatives as they were seen as outside assistance for the group. In any case, communication with them was ongoing and a good sense of their thoughts and concerns was thus had. The interview questions are given in the appendix of this chapter. The following were some of the key issues which emerged:

- The roles and objectives of the regional and national forums were unclear;
- The leadership and structure of the forum was unclear;
- People were confused as to what foodbanking was all about and as a result were eager to contribute though not sure how;
- There was clearly a great deal of work to be done that could not be covered in a forum that meets once a month;
- The idea of splitting up into working groups had been proposed and was popular amongst the interviewees;
- Along the same lines, a suggestion was put forward of a small team being created that could meet regularly and push hard to implement actions, and for the larger group to then act as a reference for them and to meet less regularly;
- The foodbank needs to be a community based and community owned programme;
- There were personal and organizational interests which could clash with the goals of the foodbank; and
- There was fear that the process would be delayed and that there would be unmet expectations.

As expected, some of the main concerns were a lack of clarity around what foodbanking is about, what the current forum's role is in establishing one and who the current leadership of the forum is. However, the general mood was positive and people were eager to contribute.

3.5 Workshop

The goals for the workshop were as follows:

1. To enhance the understanding of the foodbanking system and how the various stakeholders fit into this system;
2. To have a sense of the work required to establish a foodbank and how this fits into the foodbanking system;
3. To build working groups around different areas of work, each with a co-chair and for the group of co-chairs to form the leadership structure; and
4. For the forum to be satisfied and clear on the structural changes, leadership and the way forward.

An overview of the workshop is now given in the following subsections.

3.5.1 Introduction

The workshop started with a brief description of foodbanking by one of the GFN representatives. This was followed by a short overview of the work that had been undertaken to date, which included a summary of the key results from the interviews. The goals for the workshop were then given so that the participants could have a clear view of where they were heading, and finally, an outline for the workshop was presented. During the introduction the suggested structural change was put forward and was well received. Figure 3.4 shows the physical set-up for the workshop. Chairs and tables were arranged in a semi-circle formation toward the main wall, on which information could be displayed.

3.5.2 Listing Stakeholders and their Goals for FBCT

Participants were asked to draw up a list of stakeholder groups along with what these groups would hope to achieve from the foodbank. This was simply done by writing suggestions from the group on large sheets of white paper and sticking them on the wall with Prestik. This helped to get a

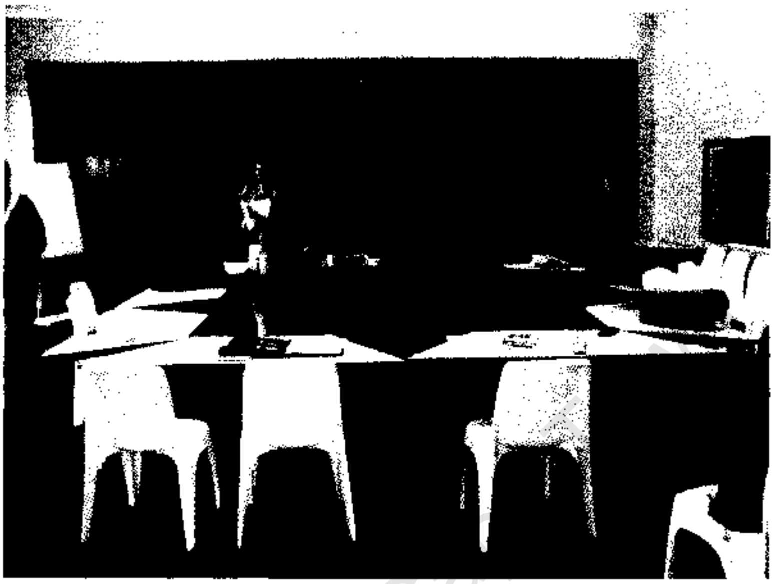


Figure 3.4: Photo of the workshop area

sense of what the goals for the foodbank are and what the various groups of stakeholders are, along with potential clashes of interest.

3.5.3 Drawing up a systems model with tasks

These sheets of paper were then moved to a different wall for later reflection if required. Using the then vacant wall a very basic systems model was put up of how food moves from "suppliers" to "FBCT" to "beneficiary NGOs" (i.e. agencies) to "end-users" . Each of these four items were written on a separate post-it and spread in the noted order across the wall. Participants were then asked, with the aid of the information from Section 3.5.2, to identify tasks that would be required to set up FBCT and keep it running. For this, each individual was given a number of post-its to write on. They were asked to write one task or idea per post-it and to place the post-its roughly where they related to the foodbank system (using the existing structure displayed on the wall). As more and more post-its were stuck on the wall, it became evident that there were a number of similar tasks/ideas emerging. Participants were then also asked to group similar concepts together. This process resulted in a visual representation of the flow of product from beginning to end, along with all of the necessary tasks required to make it happen.

3.5.4 Using the Tasks to Form Working Groups and Co-Chairs

Once similar tasks had been grouped together, the group was asked to arrange related tasks together into themes. These themes, with their tasks, would then form the basis for the work to be covered by different working groups. At this stage the themes were self-evident to everyone involved and were as follows:

- *Warehousing and operations,* which covered all issues relating to the logistical operations of the foodbank;
- *Food sourcing,* which focused on sourcing food and investigating concerns that suppliers had, as well as their expectations with regard to quality control;
- *Management,* which was concerned with issues such as organizational structure, legal processes, marketing, LIR, etc.; and
- *Community liaison,* which dealt with aspects such as the allocation of food, agency relations, rural development, etc.

Participants were then asked, provided they could commit to the time required, to write their name on a post-it and stick it on the theme where they would most like to work and/or where they could contribute most. This formed the basis for forming the working groups and ended up being fairly straightforward, although one or two names were moved to balance the groups. Importantly, no-one was allocated the "food sourcing" group. This was probably an indication of the lack of supply side representation in the forum (the expertise of the individual who represented one of the suppliers related primarily to logistics). It was decided to leave this group vacant for the time being as it was already planned that consultants would later assist in this area.

Once these groups had been formed, each group was asked to select a co-chair. The role of each co-chair was clearly defined: to provide overall leadership for the forum and for their respective working group, and to ensure that all the necessary work in their working group would be completed on time. The selection of co-chairs was also very straightforward through the natural leadership (not at all implied in a negative sense) already existing in the group, and also through who would have enough time for this role.

3.5.5 Closing stages

Once these working groups had been formed with their co-chairs, meetings were scheduled for t he different working groups and for the group of co-chairs. The full forum would then only meet once every two months as time would now be spent in the individual working groups.

3.6 Project Management

In order to progress with the establishment of the foodbank, all the tasks required for this had to be identified. Recall that an initial list of tasks was drawn up during the -problem exploration and definition" phase of research *(see* Section 3.1.1). Also, a list of tasks was developed while defining working groups in the workshop. A lot of time was then spent with the co-chairs to develop a more comprehensive list of tasks with interdependencies and associated expected times (in weeks). These tasks were categorized according to the working groups.

Tasks required from an academic point of view (i.e. for the purpose of this dissertation) were grouped in a separate category, while the category "other" was added for when expertise would need to be outsourced. Outsourced tasks would not strain the human resources of the CTFBF but rather the financial resources, though often pro bono work could be found. The various working groups were seen as the human resources for the project and the number of tasks being worked on by each working group per week were then tracked. There were also "ongoing tasks" (such as communication with government) in each working group that were considered to not occupy resources as there would be minimal amounts of work occurring at irregular intervals.

Open Workbench2 was used to construct Gantt charts with critical paths with the start date set at 9 June 2008 (roughly four weeks after the workshop). Software problems were encountered when trying to minimize project completion time while taking into account resource constraints. Tasks were therefore manually shuffled after the Open Workbench Gantt chart was produced, based on resource constraints. It was envisioned that, in order to finish the project as soon as possible, people could to an extent be transferred between working groups if required. A fair amount of intuition was

[2] Open Workbench is open source software for project management tp://www.openworkbench.org/).

used to determine the "person hours" required for each task and what each working group would be able to handle from a human resource perspective (through developing the information with the co-chairs it had become evident which tasks were more labour intensive than others, and a fair sense of each group's capabilities was acquired through the time spent with them). It was attempted to keep the maximum number of tasks for any given week (per working group and overall) at a minimum when manually shuffling tasks, after which the overall plan was checked to see if the working groups would become too strained at any point.

Three Gantt charts were generated, which are shown in Figure 3.5 and Figures 3.7 and 3.8 in the appendix of this chapter. Each shows the critical path in red, however Figure 3.7 shows the earliest date at which tasks can begin and finish; Figure :3.8 shows the latest date at which tasks can begin finish; and Figure 3.5 shows a suggested project plan such that the maximum resource requirements at any given time over the project are minimized. Emphasis was placed on Figures 3.7 and 3.8 for the forum and co-chairs as it was considered to be better to leave the responsibility of timing tasks to the co-chairs. Each project plan has its tasks grouped according to working groups for clarity. "NI" stands for "Management", for -Warehousing and operations-, -B" for -Beneficiary liaison", -A" for -Academic Work" and "S" for supplier relations or "Food Sourcing". By observing Figures 3.7 and 3.8 the co-chairs could see the earliest and latest dates by which tasks could/had to be done, and then decide how they wanted to manage their working group in order to achieve these tasks. In addition a presentation was given to the CTFBF on the project plan and the major findings. The important findings will now be pointed out, after which some of the finer details will be discussed.

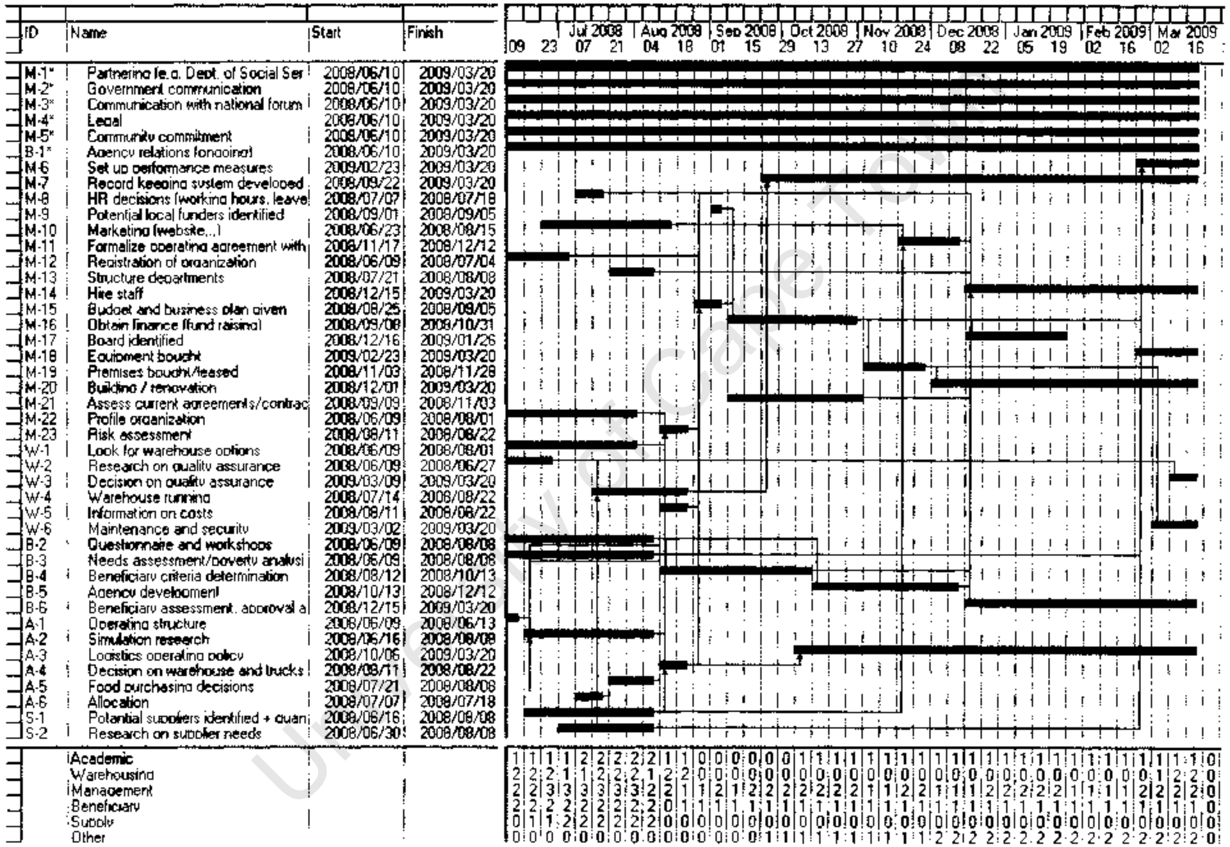


Figure 3.5: Gantt chart depicting a recommended schedule for tasks

3.6.1 Major Findings

The critical pat h is first explained, after which the importance of a specific task and its impact on the overall project is discussed. Finally, a brief sensitivity analysis is carried out.

Critical path

The critical path can be seen in Figure 3.5. The estimated scheduled completion date is 20 March 2009. However, this could be brought forward as follows.

- In order to *finish in the beginning of Mairh,* the "building/renovation" task (M-20) needs to be shortened. It is currently assumed that the renovation option will be taken, which is scheduled to take 3 months. If a warehouse were leased that required minimal work to be done, the project could be completed earlier.

- In order to *finish in the beginning of February,* -building/renovation" would need to take 7 weeks. Also, -formalizing operating agreements with suppliers" (NI-11) or "beneficiary assessment, approval and operating agreements" (B-6), which is a successor of (M-11), would need to be shortened as these would then become part of the critical path. At present (M-11) is scheduled to take 4 weeks, followed by which (B-6) is scheduled to take 14 weeks (giving a total of 18 weeks). If together these muld be shortened by 3 weeks, or if they could run concurrently, the completion date will move to 6 February 2009.

- To move the *completion date to earlier than February, (M -20) and* ((M-11) or (B-6)) would need to be shortened, as well as the tasks of "hiring staff- (M-14) and -Record keeping system developed (also IT)" (1\1-7), as these would then also become part of the critical path.

Putting a budget / business plan together and obtaining finance

Probably One of the most important findings, which is also to be expected, is that the tasks of "putting a budget/business plan together" (M-15) and "obtaining finance- (M-16), which is (M-15)'s immediate successor, are probably the most important to consider. There are several reasons for this.

1. They create a *bottle neck,*. Many tasks are required to put a budget toget her (M-15), and only once finance has been obi ained (M-16) can

many other tasks begin. There are 15 tasks necessary to put a budget together. Some of the more important ones are: Warehouse Running (W-4); Information on costs (W-5); lin decisions (M-8); Registration of organization (1\1-12), Structure departments (M-13); and Decision on warehouse and trucks (A-4), which requires prior research. Tasks that can only begin once finance has been obtained: Formalize operating agreement with suppliers (M-11) and beneficiaries (B-6); Hire staff (M-14); Board identified (M-17); Equipment bought (M-18); and Premises bought/leased (M-19).

2. They are *urgent.* Companies can often only grant funds when their yearly budgets are being reviewed, so if they receive the request too late one has to wait until the next budget review.

3. They are *variable.* The time needed to raise the finance required is difficult to predict. Funding from FBSA may be available, though they have indicated that this financing should not be counted upon. National funding would probably come through quickly if it is available, but if not, fund raising is time consuming and very unpredictable. An initial estimate of 8 weeks is given for fund raising. If this task takes longer it will delay the entire project by however much longer it takes (as it is on the critical path). The variability of the task therefore makes it high risk.

4. Finally, they are clearly *critical* - without money FBCT cannot operate.

Sensitivity analysis

A brief sensitivity analysis was carried out through observation. Attention was focused on variable tasks that could cause overall delay through changes in their completion time. These tasks are listed below.

- *Building/renovation (AI-20):* This has already been addressed, but what has not been considered is that this task has the potential to cause considerable delay if a warehouse is built from scratch or if extensive renovation is required.

- *1?ecord keeping system developed (also IT)* (A1-7): This task includes all the IT involved. Again, it is difficult to attach time estimates to this. Currently this task starts two weeks after fund raising begins. If the fund raising task is required to be completed before this task can commence (so that the right expertise can be hired), the project will be delayed by 6 weeks. The task is also variable and if it takes longer than the 6 months assigned to it, it will cause an equivalent delay in the entire project.

3.6.2 Some of the Details

The details discussed are: tasks that overlap with FBSA; "ongoing" tasks which do not have a set start or finish date; and some issues around the merging of Lions, Robin Good and Feedback.

National tasks

There are certain tasks that are crucial to the success of the project but which overlap with FBSA's responsibilities. For each of these tasks communication will be vital in determining local and national responsibilities such that work is not duplicated or omitted. There will also be a certain amount of reliance on FBSA to complete their portion of these tasks on time in order for the project to be successful and finish on time. To reduce the risk from FBSA contingency plans can also be drawn up. The tasks that overlap with FBSA are given below.

- *Record keeping system developed (also IT)* (M-7): Ideally most of the work will be done at the national level, particularly from an IT perspective, however there will be certain components that will be unique to local environments.
- *Legal (M-4):* Broad legal issues will be dealt with at the national level, however some of the details will need to be dealt with at the local level.
- *Working with suppliers (S-1):* Many potential suppliers are national organizations. The strategy for these suppliers is to reach national agreements that can then be filtered down to the local outlets. However there are also many suppliers which are unique to the local area that will need to be dealt with.
- *Identifying fanciers and obtaining finance (M-9)(M-16):* Similar to "working with suppliers", there are potential funders that are seen as -national" (who will be handled by FBSA) while the regional hinders will be handled by FBCT. "National" funding will be divided amongst FBSA and the regional foodbanks. Along these lines, FBCT will need to put forth a budget to FBSA who will then be able to supply a

certain amount of funding. FBCT will need to raise the balance, thus the sooner the amount coming from FBSA can be established the

- *1?egistration:* The task of the registration of FBSA and the regional foodbanks as an NGO/NPO has been left to FBSA.

Ongoing tasks

There were certain tasks which did not have set start and finish dates. Rather, they were ongoing throughout the project. These tasks are listed below.

- *Legal (A1-4):* Although this was specified as a single task there are in fact a number of legal issues inherent in a variety of tasks.

- *Budget (A1-15):* Although a two-week period was set for this, it was seen that many tasks had a budget component. These budgetary components were suggested to be dealt with by the individuals responsible for the tasks concerned so that this information could then be provided to the people doing the budget.

- *Communication:* "Ongoing" communication was required in a number of areas. These areas relate to agencies (B-1), partnering (M-1), government (M-2), FBSA (M-3) and community commitment (M-5).

- *"Corking 'with potential local suppliers (S-1):* An initial time period of more demanding work was given for this, though work in this area would be ongoing after this.

Although these are ongoing tasks, it was made clear to the CTFBF that this does not imply that they can be left to the last minute. On the contrary, a substantial amount of work is required during the early stages of the project.

The task of Incorporating Lions, Robin Good and Feedback

As it is envisioned that Lions, Robin Good and Feedback will merge to form FBCT, there are a number of issues to consider.

1. When writing up a "budget and business plan" (M-15), it will be important to know what equipment will be transferred as this would impact on the necessary funds to be raised.

2. Before the task of 'hiring staff" (M-14) can be addressed, it will be necessary to know which personnel will be transferred to FBCT from the merging organizations.

Appendix: Aiding the Establishment of FBCT

Figures

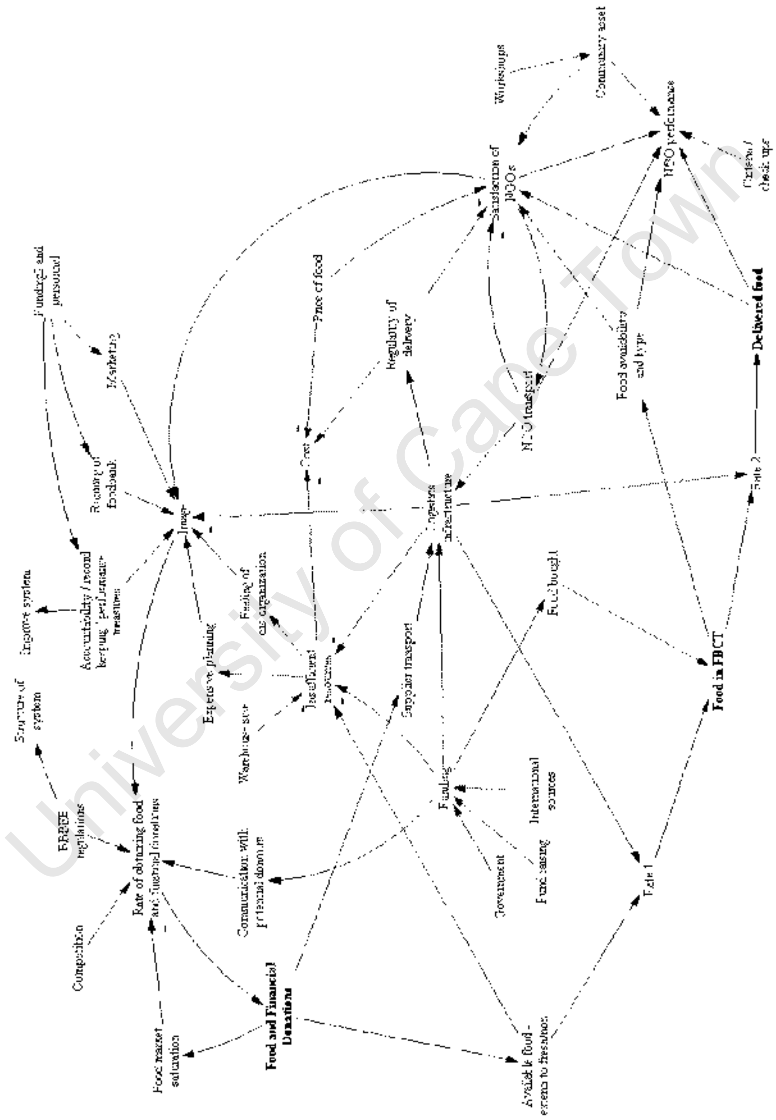


Figure 3.6: Causal loop diagram of FBCT

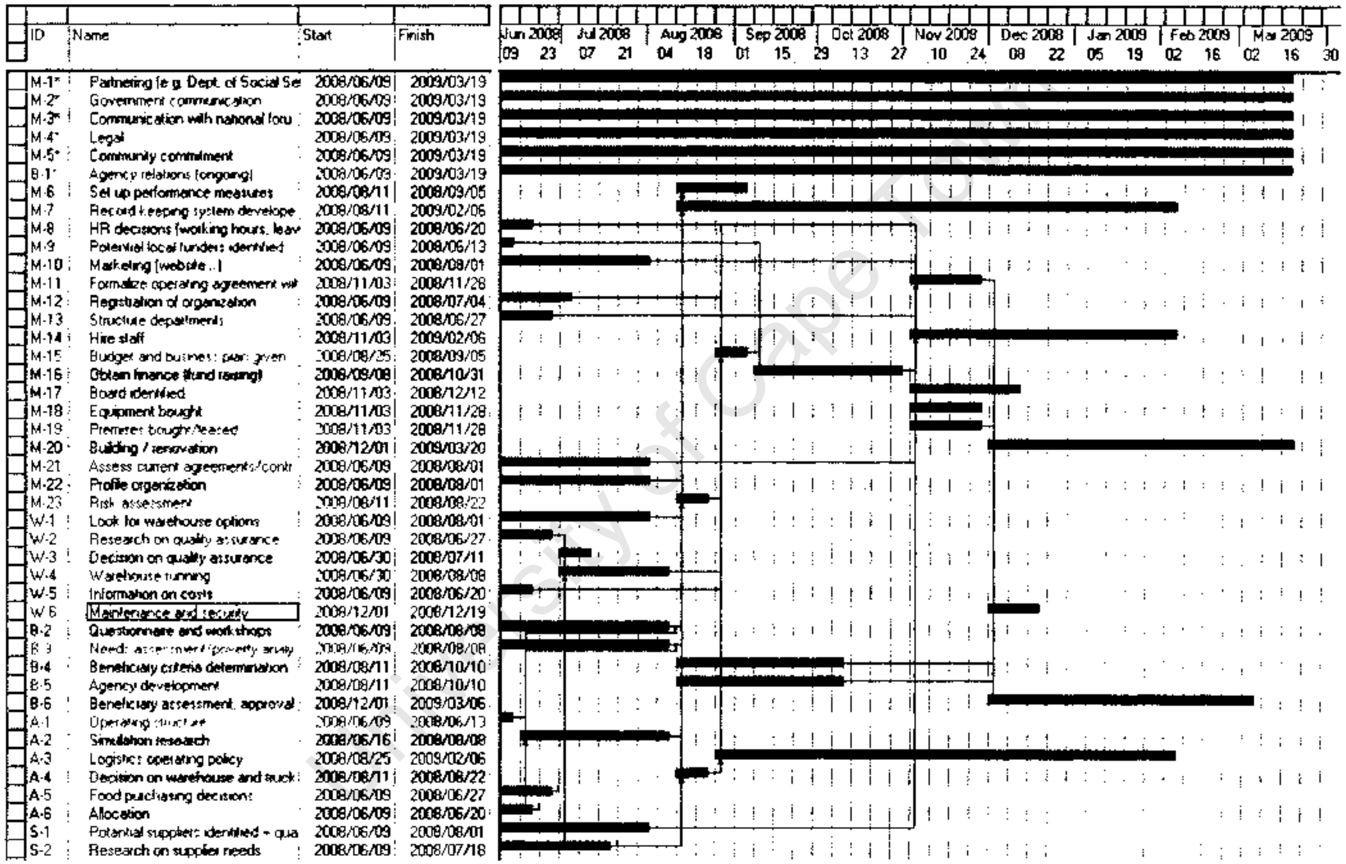


Figure 3.7: Gantt chart depicting the earliest date tasks can begin

ID	Name	Start	Finish
M-1*	Partnering (e.g. Dept. of Social Se	2008/06/10	2009/03/20
M-2*	Government communication	2008/06/10	2009/03/20
M-3*	Communication with national foru	2008/06/10	2009/03/20
M-4*	Legal	2008/06/10	2009/03/20
M-5*	Community commitment	2008/06/10	2009/03/20
B-1*	Agency relations (ongoing)	2008/06/10	2009/03/20
M-6	Set up performance measures	2009/02/23	2009/03/20
M-7	Record keeping system develope	2008/09/22	2009/03/20
M-8	HR decisions (working hours, leav	2008/08/11	2008/08/22
M-9	Potential local funders identified	2008/09/01	2008/09/05
M-10	Marketing (website...)	2008/06/30	2008/08/22
M-11	Formalize operating agreement wi	2008/11/17	2008/12/12
M-12	Registration of organization	2008/07/28	2008/08/22
M-13	Structure departments	2008/08/04	2008/08/22
M-14	Hire staff	2008/12/15	2009/03/20
M-15	Budget and business plan given	2008/08/25	2008/09/05
M-16	Obtain finance (fund raising)	2008/09/08	2008/10/31
M-17	Board identified	2009/02/09	2009/03/20
M-18	Equipment bought	2009/02/23	2009/03/20
M-19	Premises bought/leased	2008/11/03	2008/11/28
M-20	Building / renovation	2008/12/01	2009/03/20
M-21	Assess current agreements/contr	2008/10/20	2008/12/12
M-22	Profile organization	2008/06/16	2008/08/08
M-23	Risk assessment	2008/08/11	2008/08/22
W-1	Look for warehouse options	2008/06/16	2008/08/08
W-2	Research on quality assurance	2008/06/23	2008/07/11
W-3	Decision on quality assurance	2009/03/09	2009/03/20
W-4	Warehouse running	2008/07/14	2008/08/22
W-5	Information on costs	2008/08/11	2008/08/22
W-6	Maintenance and security	2009/03/02	2009/03/20
B-2	Questionnaire and workshops	2008/06/09	2008/08/08
B-3	Needs assessment/poverty analy	2008/06/09	2008/08/08
B-4	Beneficiary criteria determination	2008/10/13	2008/12/12
B-5	Agency development	2008/10/13	2008/12/12
B-6	Beneficiary assessment, approval	2008/12/15	2009/03/20
A-1	Operating structure	2008/06/09	2008/06/13
A-2	Simulation research	2008/06/16	2008/08/08
A-3	Logistics operating policy	2008/10/06	2009/03/20
A-4	Decision on warehouse and truck	2008/08/11	2008/08/22
A-5	Food purchasing decisions	2008/07/21	2008/08/08
A-6	Allocation	2008/07/28	2008/08/08
S-1	Potential suppliers identified + qua	2008/06/16	2008/08/08
S-2	Research on supplier needs	2008/06/30	2008/08/08

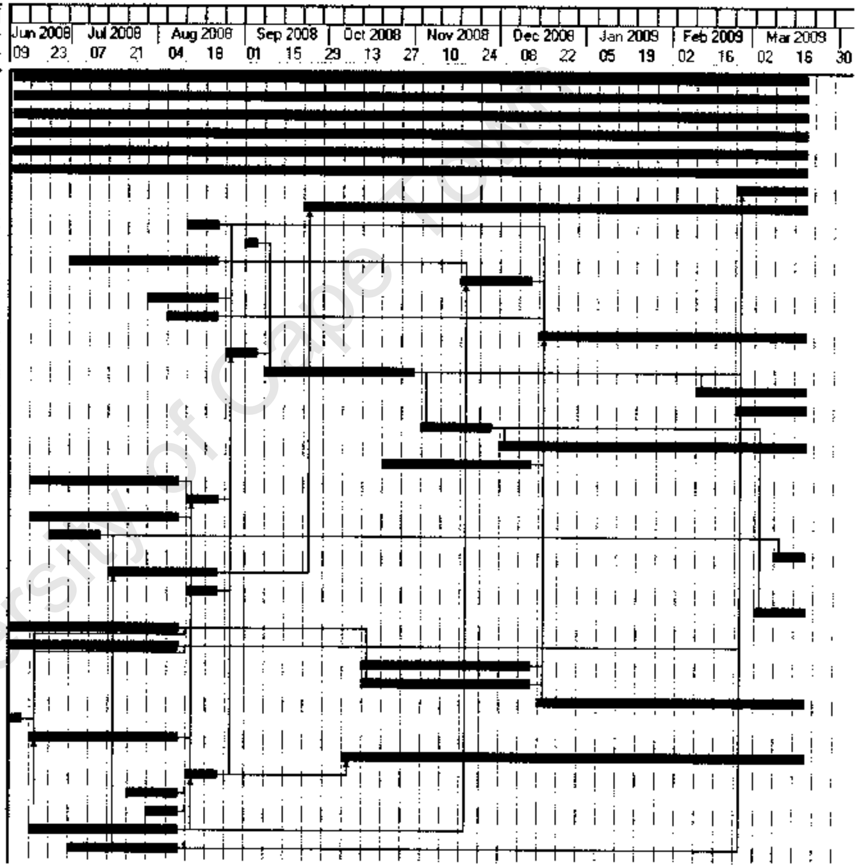


Figure 3.8: Gantt chart depicting the latest date tasks can end

Interview Questions

Note: Some questions were added at a later stage as they became beneficial, therefore not all interviews have responses to these questions. Also, some responses to questions would overlap with other questions and in general intuition was used to guide interviews.

Questions for NGOs

1. *How* do you see the problem of hunger'? (needs / performance measures)
2. Ifow do you view the foodbank? (how will it address the problem of hunger and make a difference?)
3. How do you currently obtain food'? What quantity are you obtaining?
4. What How do you as an NGO hope to get out of the foodbank?
5. do you view the current forum? (Its ability to get a foodbank up and running)
6. NiVhat decisions will need to be made around your area (NGO)?
7. What problem areas do you foresee coming up?
8. Any other personal concerns or points/issues you would like to raise?

NGOs currently doing foodbank type work

1. *How* do you see the problem of hunger'? (needs / performance measures)
2. How do you view the foodbank? (how will it address the problem of hunger and make a difference?)
3. How do you view the current forum? (Its ability to get a foodbank and running)
4. What decisions will need to be made around your area (manager)?
5. What problem areas do you foresee coming up?
6. Any other personal concerns or points/issues you would like to raise?
7. Look at systems model

Suppliers: TWIT focus on question

How do you see the problem of hunger? (needs / performance measures)

2. How do you view the foodbank? (how will it address the problem of hunger and make a difference?)

3. What do you currently do with excess food? What quantity?

4. What do you as a supplier hope to get out of the foodbank?

5. How do you view the current forum? (Its ability to get a foodbank and running)

6. What decisions will need to be made around your area (supplier)?

7. What problem areas do you foresee coming up'?

8. Any other personal concerns or points/issues you would like to raise?

Chapter 4

Warehouse Size

FoodBank Cape Town was faced with the problem of obtaining a suitable warehouse for its operations. Two of the most important criteria identified were the size awl location of the warehouse. This chapter deals with modelling what size warehouse would be ideal. The subsequent chapter then addresses modelling optimal warehouse location. The research of these two chapters together formed the basis for a decision to be made on a particular warehouse in Philippi, which is explained in Chapter 7. After FBCT decided to take the space, a problem arose as to whether to lease half of the space in Philippi for a short period (after which the full space would be taken) or to lease the full space from the outset. As this problem is relatively short and relates to the warehouse size, it is discussed at the end of this chapter (Section 4.5.5).

The warehouse size methodology is first discussed. From this, it becomes evident that information is necessary on how food will be stored as well as the initial and future inflows, thus the subsequent sections discuss these in detail. The model for establishing warehouse size is then built, drawing on information from previous sections. An analysis with sensitivity is subsequently carried out with focus on current inflows and anticipated future inflows. Filially, the specific problem at the Philippi warehouse is dealt with.

Through studying a typical foodbank's operations, some side objectives to warehouse size arose. These side objectives are also dealt with awl include: determining the amount of cold and ambient storage required; the volume of daily waste; and the volume of food needing to be sorted, cleaned, defaced and packaged daily.

4.1 Methodology

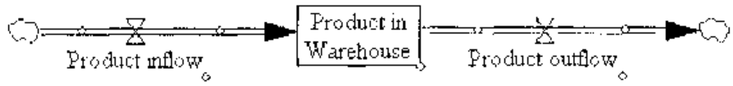


Figure 4.1: Systems dynamics representation of warehouse stock

Using systems dynamics terminology, Figure 4.1 illustrates a very simple model of the warehouse size problem. Inflows and outflows differ in their nature: inflows can be regarded as exogenous (the foodbank takes whatever is available) whereas out flows are endogenous (the amount of food allocated to agencies on a daily basis is a decision made by the foodbank). The stock at the warehouse would then be the resultant nett of outflows subtracted from inflows at any given time. The overall approach for the research was therefore as follows:

1. To investigate how food would be stored in a typical foodbank warehouse and the space available for this in order to measure the relationship between the size of the warehouse and the actual volume of food storage available;
2. To study current inflows (Lions, Robin Good and Feedback) and anticipated future inflows to be able to correctly model them;
3. To use (1) and (2) to construct a model based on the system given in Figure 4.1; and
4. To use different inflows and operating rules for outflows in order to analyse their impact on the required warehouse size.

It would have been helpful to analyse data on current outflows as well in order to learn from actual operations. However, Lions and Feedback operated under a system where the inflows for the day equalled the outflows for the day because of the perishability of their products and a lack of storage space; and data on Robin Good, the only organization that utilized storage space, was not readily available.

An Excel model was envisioned whereby, for each time period:

1. A level of inflow would be simulated;
2. An operating rule would determine the outflow; and
3. The nett volume of food would then be stored in the warehouse at the end of the time period.

4.2 Analysis of Storage

There were four critical areas to consider with regard to storage:

1. The different types of storage areas;
2. The relationship between total warehouse floor space (m2) and floor space available for storage (m2);
3. The relationship between storage floor space (1112) and volume of storage (m3); and
4. Conversion of food weights to volumes, as dat a on current inflows was recorded only as weights.

Each of these areas is now discussed in the ensuing subsections.

4.2.1 Types of Storage Areas

A GFN representative (T. Ives) with experience in operating food banks in the US was available to give input on how a typical foodbank would operate. In addition, these recommendations were discussed with the Feedback regional coordinator (P. Andries) in order to make sure they were locally applicable. The GFN representative gave examples of floor plan layouts from the US, thus giving an understanding of the flow of products. Different storage types were discussed, the types of products that would go into each storage area and the respective shelf lives of these products (see Table 4.8 in the appendix of this chapter). Three storage areas are required.

1. *Ambient storag e with racking.* All non-perishable products will be racked in an area of room temperature.
2. *Ambient storage 'without racking.* This consists of perishable products that do not require cold storage (e.g. bakery produce). As a result of their perishability, these products will operate on a one-day cycle. All products held in this storage area overnight would be emptied

out the following day before trucks return with new products. Therefore, ambient storage without racking must be large enough to handle roughly the maximum of one day's inflows for this area. Due to the fast turnover time, it would be problematic to rack these products and they would therefore be stacked in crates on the ground.

3. *Cold storage.* The products entering here will consist mainly of fresh fruit, fresh vegetables and dairy. As these products are perishable, this storage area will act in the same way as ambient storage without racking and will be required to handle roughly the maximum FBCT would receive in a day.

A foodbank may well have frozen storage as well, however this was omitted in this dissertation. Through analysis of cunent inflows (Section 1.3), it was found that the foodbank will have no frozen storage to deal with at its opening. Recommendations on frozen storage would therefore he based solely on future inflow predictions, for which there is very little certainty. It was decided to handle frozen products (typically meat and fish) in the same manner as other over-night cold products. As the amount of frozen storage is small in comparison to other storage areas, this assumption will have little impact on the warehouse size required.

4.2.2 Warehouse Layout

The fundamental question with regard to warehouse layout was: "Given a certain warehouse size, how much space would be available for actual storage?". hi order to establish this relationship a spreadsheet was given to a GFN representative to fill out. On this spreadsheet were the various functional areas of the warehouse identified during the meetings discussed in Section 4.2.1. These areas included receiving and dispatch areas, storage areas, a sorting and cleaning area, office space and free space between these to move. The GFN representative was then asked to fill in how many square metres would be given to each functional area for warehouse sizes of 12001112, 25001112 and 50001112. From this, a relationship of warehouse size to storage space could be determined.

Unfortunately, the GFN representative was not willing to do this for the 12001112 case as he felt, from his experience, that this size warehouse would be too small. With two points available, only a linear relationship could be determined. This resulted in the warehouse needing to he larger than 8001112 for there to be any storage space. Intuitively, storage space would be available for warehouses far smaller than 8001112 as an 800m2 warehouse is fairly large. An alternative function was therefore sought.

Although typically some minimum warehouse size would be required before storage space could commence (denoted as "fixed space"), it was observed that all the listed functional areas were variable in size and would increase with larger operations and warehouse size, even in extreme cases. As an example, Robin Good operated from a small space of about 150m2. In order to maximize storage space, "office space" consisted of only a desk 111d computer, taking up about 101112. The point (0; 0) was therefore added and a quadratic function fitted in order to capture the increasing returns to scale of storage space on warehouse size. This fit can be seen in Figure 4.2. The resultant equation is:

$$s = 0.00004w^2 + 0.36w; \tag{4.1}$$

where s and w denote storage space and warehouse size in square metres respectively. A concern would be that, as a quadratic function, storage space increases at an increasing rate indefinitely. After 80001112, each extra square metre of space would result in more than 1m2 of extra storage space. However, the warehouse will almost certainly be between 5001112 and 5000m2, and over this range the function is a reasonable approximation.

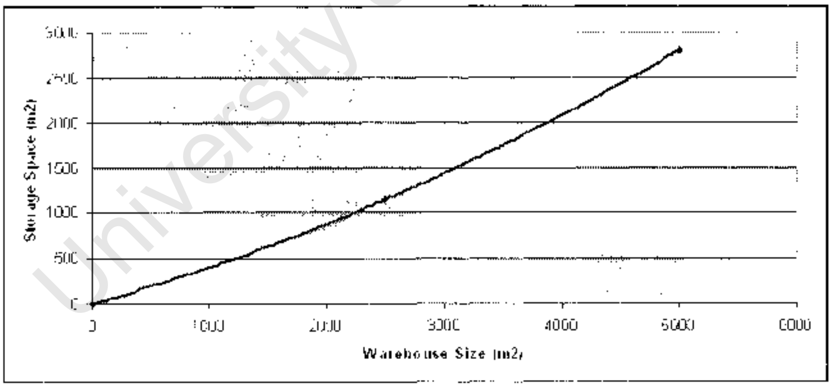


Figure 4.2: Plot of proportion of storage space against warehouse size

4.2.3 Converting Storage Floor Space (m2) to Volume of Storage Space (m3)

For each of the storage types identified, a ratio Of floor space to volume of products was required. Information on these was provided by CTN.

Ambient storage with racking

After incorporating space to move between aisles, a typical racking layout has roughly 40% of the floor space covered by actual racking. When products are racked, they go on pallets, of which it was recommended that three be stacked above each other, each two metres apart. Through observation and measurement of a food company's racking, it was determined that there was roughly a 20% loss in height volume when racking. Therefore, the final result is as follows: for each .rm2 of storage space, there would be (0.4)(0.8)(3 x 2)x = 1.92xm3 of storage available.

Cold storage

There are three options for cold storage: a cold room without racking, a cold room with racking or a container (which does not accommodate racking). Due to the fast turnover of the products in cold storage, a cold room with racking is problematic. Products can be stacked 2 metres high in crates for both a cold room without racking and a container. The resultant choice of a cold room without racking or a container is therefore negligent to the storage problem. There is no need for space between products as there is no need to get specific products at certain times. It was estimated through observation of Feedback's operations (who used crates for stacking) that there would be about a 25% loss in volume through loose packing, crates taking up space, crates not being stacked up to the highest point of the container or cold room, etc. Therefore, for each square metre, one would get 75% of 2 cubic metres = 1.5 cubic metres.

Ambient storage without racking

This was handled in the same way as cold storage where products are stacked 2 metres high in crates and a 25% loss in volume is incurred.

4.2.4 Converting Food Weights to Volumes

There was no data readily available on this and people's judgement, while adequate, seemed to not be very accurate. It was therefore decided to measure a sample of products, which were obtained from a local supermarket. Categories of food types were identified using Table 4.8 and for each category a sample of products was measured. Volumes were measured using a tape measure and weights were given on the packaging of the products. This data is given in Table 4.9 in the appendix of this chapter. For increased accuracy, a larger sample was generally taken for products that were seen to be common to the foodbank. For each product, a volume to weight ratio was calculated. This was then averaged over the range of products for a particular category so that a volume to weight ratio was produced for each food category. This data is recorded in Table 4.8 in the appendix of this chapter.

4.3 Analysis of Inflows

rfhere were two steps involved in attempting to model/predict inflows: firstly, to model t he inflows from Lions, Robin Good and Feedback (which would constitute the inflows at the opening of FBCT), and secondly, to estimate short- and long-term growth.

Inflows can broadly be broken up into two categories.

1. *Perishables.* This consists of all fresh food ind, as explained in Section 4.2.1, will stay for at most one night in the foodbank. This food generally comes in small quantities on a daily basis from a large number of retailers.

2. *Non-perishables. This* is all food with a long shelf life and will go into "ambient storage with racking". This food generally conies in large quantities from a small number of manufacturers and is received infrequently (each manufacturer may give a large donation on average every month or two).

Due to the large differences in the nature of these inflows, it was decided to model them separately. In each case, it was necessary to model both the weight of inflow and the composition of inflow (as per Table 4.8 in the appendix of this chapter). The latter would determine the volume to weight ratio as well as, in the case of perishable products, the storage type required.

In the following subsections each of Feedback's, Lions' and Robin Good's inflows is discussed, after which anticipated future inflows are examined.

4.3.1 Feedback

Feedback was the only organization from which an historical record of inflows was available. A detailed analysis was therefore carried out (distribution fitting, equality of time periods using ANOVA, time series analysis, etc.) as certain results could then be transferred to Lions and Robin Good where applicable. At the start of the analysis period, Feedback only dealt with perishable products from a large number of retailers, however during the data analysis period they began to receive non-perishable products from manufacturers as well. The emphasis of the data analysis is therefore on the perishable products though the small sample of non-perishable data is also examined. Data analysis of the perishables is first discussed in the ensuing subsections, after which non-perishable products are discussed.

Data formatting and cleaning

Data by region (Cape Town, Johannesburg, Pietermaritzburg and Durban) were obtained from Feedback in Excel format, however only the Cape Town data was worked with as this was directly relevant to I he field of study. The data was very detailed and available from January 2003 until April 2008. Every i ransaction between a specific. supplier and agency was recorded as a separate row in Excel. The level of detail resulted in about 60 transactions per day, each of which had information on date, supplier name, agency name and the weight of the products in kilograms.

There were three main areas in which data errors were identified.

1. *Naming of suppliers.* Supplier names were inconsistently entered.
2. *Incorrect dates.* Sonic incorrect dates were identified. These errors were omitted from the analysis as they were minor and excessive effort would be needed to correct them.
3. *incorrect 'weights.* Errors (probably due to incorrect data capturing) were detected by using scatter plots of daily total weights. Values that were abnormally large could then be checked and corrected if necessary. An example of this was an apparent donation of 12 tons (beyond the truck capacity of the vehicle collecting it) from a supplier that usually gives about 100kg per donation.

Exploratory data analysis for weights summed over all suppliers

Exploratory data analysis was first carried out on the food weights of all Feedback's suppliers. Daily, weekly and monthly totals were analysed, but for conciseness only a sample of plots are displayed here.

It can be seen from the monthly totals (Figure 4.3) that inflows have remained fairly constant throughout Feedback's history. For the histograms (Figures 4.4 and 4.5), best-fit curves are displayed, although the actual distribution testing is only later explained. The daily data is heavily skewed to the right. Intuitively this seems correct as there will be the occasional large donation that would result in a long tail on the histogram. The data could be modelled by Gamma or Log-normal distributions. The same can be said for the weekly data (not displayed), except that the skewness is less prominent. The monthly data is more closely normally distributed. The sum of Gamma distribution variables tend to follow a normal distribution,

seems to be consistent with the above data

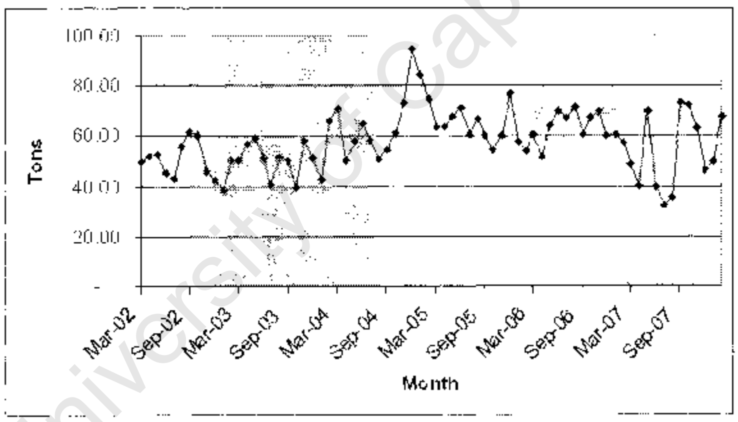


Figure 4.3: Time sequence plot of Feedback's monthly food weights

Exploratory data analysis by individual suppliers

Figure 4.6 shows Box and Whisker plots of the weekly inflows from five different suppliers. A diverse group was chosen: there is a bread manufacturer, two different supermarkets and a restaurant. It can be seen that there is large variation both between suppliers and within suppliers, as well as a large number of zero values within suppliers. The large variation between

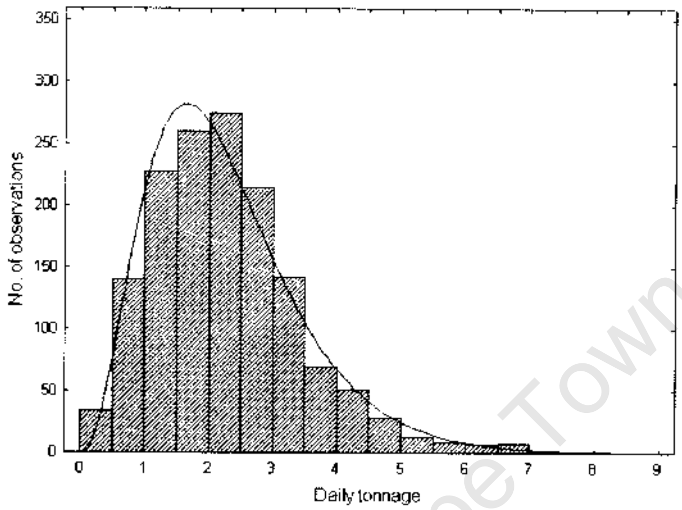


Figure 4.4: Histogram of actual daily weights with the best fitted distribution imposed

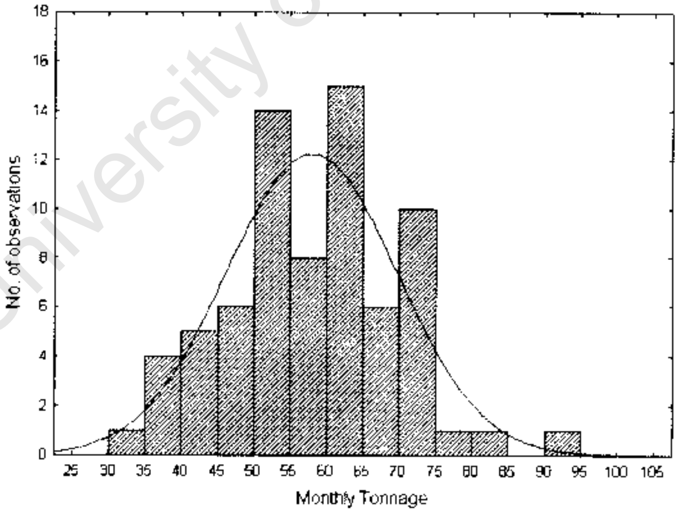


Figure 4.5: Histogram of actual monthly weights with the best fitted distribution imposed

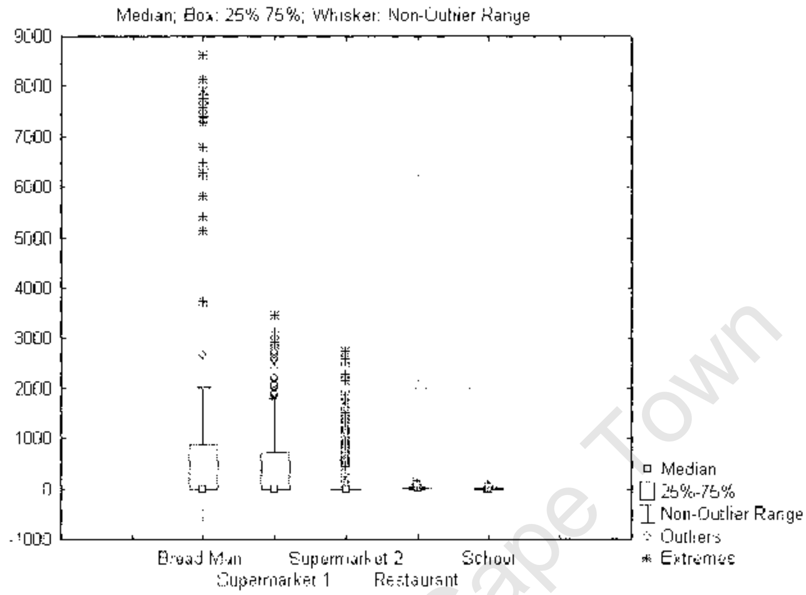


Figure 4.6: Box and Whisker plots of the weekly inflows from five different suppliers

suppliers is expected as different sized organizations will supply different volumes. The variation within suppliers conies both from expected statistical variation and a "stop-start" nature of food from suppliers. Suppliers would typically give for a period of time, stop for a period of time, start again, etc.; which accounts for the large number of zero values.

Figure 4.7 shows the number of suppliers giving food to Feedback each week. Diminishing growth can be seen with considerable variability as well. Considering that Feedback has about 115 suppliers listed over the time period it shows that only a portion of these donors are giving in any one week.

Distribution fitting

The Normal, Gamma and Log-normal distributions were fitted for each of the daily, weekly and monthly data. The Chi-square, goodness of fit test was used to test how well distributions fitted, with the associated p-values shown in Table 4.1. In addition to the Chi-square test, the Lilliefors test was used to test the monthly data for normality. This is because the Chi-

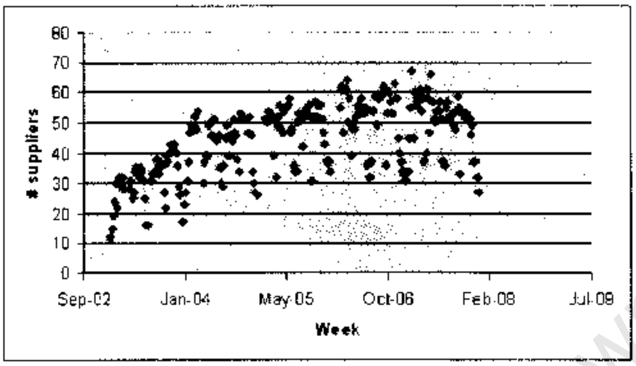


Figure 4.7: Number of suppliers providing food during a week

Table 4.1: Results from the Chi-square, goodness of fit tests for the Normal, Gamma and Log-normal distributions on the daily, weekly and monthly data. Degrees of freedom are given in brackets after the test statistic

	Daily		Weekly		Monthly	
Distribution	Test Stat. (*dof*)	*p*-value	Test Stat. (*dof*)	*p*-value	Test Stat. (*dof*)	*p*-value
Normal	142.8 (10)	0	6.8 (5)	0.2	9.2 (5)	0.1
Gamma	23.4 (11)	0.02	8.7 (5)	0.12	7.1 (5)	0.21
Log-normal	127.9 (14)	0	17.6 (6)	0.01	6.31 (4)	0.18

square test requires groupings of at least 5, which would "lose" the upper outliers of the histogram when grouping them. The Lilliefors test is non-parametric and also more sensitive to non-normality. The Lilliefors test statistic for the monthly data was 0.056. The critical value for a sample size of 72 and a significance level of 0.05 is 0.104. A value of more than this indicates a significant result, thus the null hypothesis that the data is normally distributed is not rejected.

It can be seen from the results that it was difficult to fit a distribution on the daily data, possibly due to the large sample size giving large power. The Gamma distribution gave the best fit, though the fit was not good as a p-value of only 0.02 was obtained. The Normal and Chi-square distributions were the best fits for the weekly and monthly inflows respectively. The actual

Table 4.3: Food proportions for Feedback

Food Type	Proportion
Fresh vegetables	0.41
Bakery	0.33
Fresh fruit	0.25
Dairy	0.02

- The end of the month was tested against the remainder (first 24 days) for inequality using an ANOVA and found to be insignificant.

- Different days of the week were tested using the Kruskal-Wallis Test (as the daily data is not normally distributed) and found to be significant. A multiple comparisons test was then carried out and three distinct groups were found: (a)"Tuesday, Thursday and Friday" was higher than (b) "Monday and Wednesday" by 22%, which was higher than (c)"Saturday" by 92% (Sundays were omitted as Feedback does not operate on this day). It was thought that the reason for the large decrease on Saturdays was that Feedback used fewer drivers on Saturday, though after speaking with the Feedback logistical coordinator it seemed that their limited operations are partially induced by the fact that fewer stores give on this day.

Time series analysis

Time series analysis was carried out on the monthly, weekly and daily data. The methodology was as follows.

- Natural logs were taken if the variance of the data needed to be stabilized, which was found to be the case for the weekly data.

- The Augmented Dickey-Fuller Test was used to check for stationarity, which was found to be significant for all of the data (i.e. the data was concluded to be stationary).

- A number of AIIIMA models were fitted to each data series with the assistance of a correlogram. The Akaike information criterion was used to determine which model gave the best fit and the significant AR and MA terms observed.

Table 4.4: Non-perishable tonnage received by Feedback from its manufacturer suppliers

	Man. 1	Man. 2	Man. 3	Man. 4	Total
April 2008	4.7				4.7
May 2008	64.4				64.4
June 2008	10		6		16
July 2008	7.5	1.8			9.3
Aug. 2008				60	60
Sep. 2008	1.6				1.6
Oct. 2008	1				1
Nov. 2008	26.4				26.4

It was found that when modelling daily data, there is a significant lag with the previous three days as well as the same weekday's of the previous 4 weeks. However, the model with the lowest AIC was the one with no AR, or NIA terms, showing that although there is a significant correlation, the predictive power of previous terms is weak. The same results were found for the weekly and monthly data.

Non-perishable products

During the course of this research, Feedback began to receive donations of non-perishable products from manufacturers and rented warehouse space to keep this stock. The data of these inflows can be seen in Table 4.4. The use of this data for modelling inflows will be discussed in Section 4.4.2.

4.3.2 Lions

As there was no actual data on historical inflows for Lions, information was reliant on members' knowledge. The coordinator of the Cape Town Lions food project (S. McPherson) was available for questioning. He stated that Lions in Cape Town receives food from all of the stores of a certain supermarket chain in the greater Cape Town area. In order to approximate the total weight that would come from these stores it was decided to estimate the average weight supplied per store and to multiply this by the total number of stores (58). As with Feedback, the average proportional break down of various food types was also asked (Table 4.5). In addition, estimates

Table 4.5: Food proportions for Lions

Food Type	Proportion
Fresh vegetables	0.61
Bakery	0.28
Fresh fruit	0.11

were given on the recovery rates (proportion of food fit for consumption) of different types of products and the proportion that would be loose and need packaging for different types of products.

As will later become clear, Lions' operations made up the bulk of current inflow therefore it was necessary to get as accurate an estimate as possible for their inflows. Therefore, the food type propofflons were compared with the estimates for the supermarkets supplying Feedback (see Table 4.2) for assurance and were found to be fairly similar. In addition, the weight per supermarket was estimated using Feedback's data and compared to that for Lions. These two estimates for weight per store are now discussed and compared.

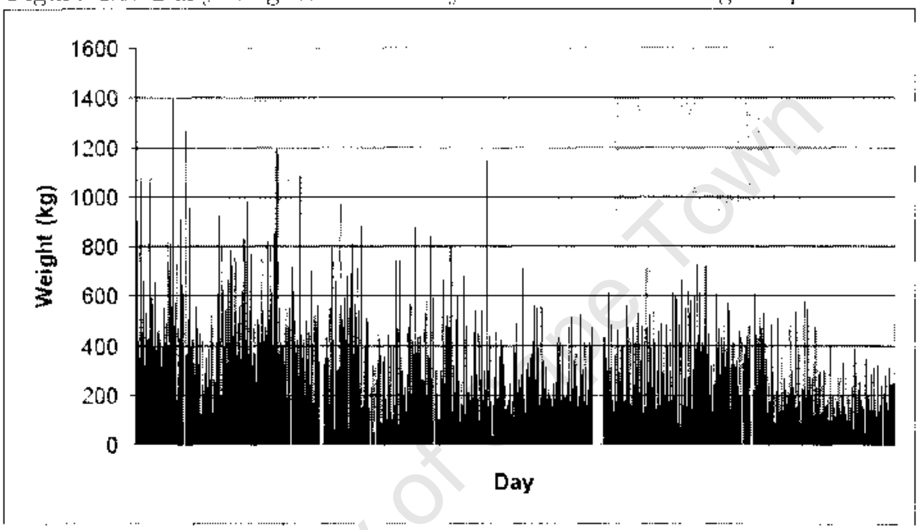
Estimate based on human judgement

The measure most tangible to the individual for estimating the average per store was financial. This was given at an average of R5,000 per store per day (although it is realized that such subjective judgements may be liable to known cognitive biases [Kahneman et al., 1982]). 11/kg values were estimated for the relevant food types. A small Excel model was created whereby the weight of one category would be input. From the proportions given, the weights of the other categories could be determined and from the R/kg values the total financial value calculated. The initial input value was altered until the financial value of the sum of all categories was R5,000. The total weight corresponding to this amount was 382 kg. This value was relayed to the Lions coordinator for verification, which he confirmed.

Estimate based on Feedback's data

Over its history, Feedback was supplied with food from seven supermarkets from the same retailer. The methodology was to estimate an average for each store and to subsequently average this over all stores. However, coinplications i-irose as there was a general decrease in amounts supplied over time for some of the stores, to the extent that only three of the original seven stores remained at the time of the analysis. Figure 4.8 illustrates the weight of food received from a single store over a period of time.

Figure 4.8: Daily weights received by Feedback from a single supermarket



The Feedback logistic's coordinator offered the following reasons for these drops in weights.

1. The main reason cited was competition: some stores decided to also donate to other organizations in surrounding areas. This tended to result in a gradual decline of supplies to Feedback until eventually the relationship ended.

2. Tough economic times resulting in better waste management at stores.

3. At t hues suppliers were difficult to work with by making drivers wait and not ensuring the food is properly cared for. Eventually, it would be more beneficial to end the relationship with the supplier and spend resources elsewhere.

4. Sometimes bar-coding issues would arise on the supplier side, resulting in food not being released.

It was noted that (1) may become less relevant with the advent of the foodbank and (2) would decrease in the long-term, which would possibly result in weights of food donations returning to their peaks over Feedback's history. It should also be noted that, although some of the supermarkets supplying Feedback ceased to be suppliers, this would not be the case for Lions as they have a long-term agreement with the supermarket chain that supplies them. It was therefore decided to have two estimates.

1. AI/ *estimate based on current inflows.*

   Data for the three remaining stores was used for the period of July 2007 to June 2008. For each store, a daily average weight donated was calculated. The average of these was 422kg. with a 90% confidence interval of 88kg to 156kg per day.

2. *An estimate assuming that /weights would return to what they used to be.*

   The daily weights of food donated by each store were first observed. A sample of data for each store was then taken from when the store started giving to Feedback to when weights from the store began to decrease. An overall average and confidence interval were calculated as before and found to be 271kg and (174kg, 369kg) respectively.

Further statistical tests over the relatively stable period of July 2007 to June 2008 were carried out on the three remaining stores, yielding the following conclusions.

- The Gamma distribution gave a good fit with p-values of 0.15, 0.05 and 0.4 obtained for Chi-Square Goodness of Fit tests. The parameters used were (2; 68), (3; 42) and (1.9; 56).
- The Kruskal-Wallis Test was used to test 14 a difference in the amounts donated on different days of the week. A total of 10 tests were done and a significance level of 0.005 was therefore used for each test in order to ensure an overall significance level of 0.05. The only significant difference was that of Thursdays' donations being smaller than Mondays' (p-value of 0.0049). Importantly, the amount donated on Saturday was not found to be smaller than other days (a concern from previous data analysis).
- A time series analysis was carried out but no significant trends or All/MA terms were found.

- The average observed correlation between the stores close to zero, which gives a basis for assuming independence of daily inflows between stores.

Overall estimate for weight per store

Given the rough similarities in the weights received per store by Feedback (275kg when they were giving their largest donations) and Lions (382kg), further analysis was based on a nominal estimate of 300kg (greater emphasis was placed on Feedback's estimate as it came from actual data). For purposes of sensitivity analysis, weights on the range 150kg to 400kg were considered.

4.3.3 Robin Good

As stated previously, information from Robin Good was unavailable, however from speaking with them and visiting their warehouse it seemed that the scale of their inflows was about 20(X, of those of Feedback's, with roughly 50(X being perishable. The perishable inflows were therefore assumed to follow the same characteristics (e.g. food proportions) as Feedback. Non-perishable inflows tended to come on a day to day basis and -were therefore far more consistent in comparison to Feedback's non-perishable inflows.

4.3.4 Anticipated Additional Inflows

With regard to growth in perishables, it was noted that no meat or dairy was being collected by Lions due to the lack of cold chain infrastructure. However, with the advent of the foodbank, this infrastructure will be in Place and perishable inflows can therefore be expected. Members of Lions estimated that the weight of these products would be roughly equal to the weight already received, with roughly equal weights of dairy and meat expected. If the foodbank is a success, short-term growth (within 2 years) for perishables was estimated to consist of obtaining all of the dairy and meat from the supermarkets supplying Lions as well as another supermarket of the same size. No significant growth was expected from the smaller stores that Feedback typically dealt with therefore growth in this area is not added. Medium to long-term growth (longer than two years) would include reaching farmers, etc. and was approximated at three extra supermarket chains the same size of Lions' (with dairy and meat added as well). These growth estimates were obtained through informal discussions with members of FBCT.

At the time of research, two consultants were having discussions with major suppliers on behalf of FBSA (with particular emphasis 011 manufacturers) in order to assess their commitment and estimate their associated inflow quantities. They found that companies showed a keen interest but were only willing to commit to FBSA when they saw foodbanks in operation. Therefore, with the assumption of success, steady increases can be expected. Unfortunately, virtually no data could be obtained as to anticipated volumes. Nonetheless, rough estimates were made which will be discussed.

4.4 Model Building

It was decided to create two models to simulate stock level requirements.

1. One to handle perishable products in order to assess the amount of cold storage and ambient storage without racking required. Here there would be no need to keep track of left-over stock from day to day as everything that comes in on a particular day goes out the following day (see Section 4.2.1).

2. One to handle non-perishable products. Here the model would need to keep track of the amount of left-over stock from time period to time period.

The warehouse requirements for each are then determined in Section 4.5, from which an actual warehouse size is obtained.

4.4.1 Warehouse Requirements for Perishables

Perishable food can be categorized according to source (Lions, Feedback or Robin Good) and type (bakery, fresh vegetables, fresh fruit, dairy or meat according to Table 4.8). Let i = 1, 2, 3 be the source of perishable product, = 1, 2, ..., 5 be the type of product and wo be the weight of the products from source i and of type j. In the ensuing subsection it is argued that it is reasonable to assume that the daily weight from each food source is normally distributed. For simplicity, it is therefore assumed that each wo follows an independent Normal distribution. The subsequent subsection derives the mean and variance for each wu. The last subsection then uses the wu's to calculate the distribution of the volume of food going int o different storage types (j), from which required sizes can be inferred.

Rationale for food sources following Normal distributions

It was previously shown that there was a basis for assuming independence between the supermarkets supplying Feedback (Section 4.3.2). As Lions is supplied by a large number of supermarkets, it is also assumed that inflows from these supermarkets will be independent and that, by the central limit theorem, the sum of weight of their food (and hence from Lions) will follow a Normal distribution. In order to calculate the mean and variance of this distribution, the average mean and variance per store was calculated using the three stores supplying Feedback over the period July 2007 to June 2008. As the supermarkets supplying Lions gave more food per store than the supermarkets supplying Feedback, the mean and variance were scaled up accordingly. The average mean and variance were then each multiplied by 58 to give the overall distribution.

The sum of Feedback's suppliers showed a more complicated distribution from day to day. It contained a time series component stretching over about three weeks, different days of the week had different means and the daily totals followed a Gamma distribution. However, as Feedback's volumes are roughly 10% of those of Lions', there was little loss in modelling Feedback's inflows by a Normal distribution. The mean and variance of Feedback's inflows were calculated and used as the parameters for this Normal distribution.

In the same vein, Robin Good's perishable volumes (about 10% of that of Feedback's) were also modelled with a Normal distribution. This simplificat ion is further just ified by the fact that future growth is largely expected to come from supermarket chains, which would increase the dominance of t he Lions type of inflow (supermarkets). As no data was available for Robin Good, the mean and variance parameters calculated for Feedback were simply scaled up by 10% to incorporate the extra volume. For the remainder of the analysis i will therefore be restricted to 1 and 2.

Calculating the mean and variance for each *wu*

A distribution is required for each *wu.* As data is only available at the level of each source i, a Normal distribution is assumed for *wo* and the mean and variance are inferred from the data on fOod sources. Let *pi* and *di2:* be the calculated mean and variance respectively for each food source i. Information is also available for the proportion of food from source i and of type j (see Tables 4.3 and 4.5), which will be denoted Au. By the definition of proportion, the mean for *wu* is *Auit,.* Let IV, be the total weight of food from source i, which is normally distributed. Suppose that the variance of w_{ij} is τ_{ij}^2. Then $Var[W_i]$ ($= \sigma_i^2$ by definition) is $\sum_j \tau_{ij}^2$. As an approximation for the purposes of planning, it is assumed that $\tau_{ij}^2 \approx \lambda_{ij}\sigma_i^2$, which gives the needed equality (as $\sum_j \lambda_{ij}\sigma_i^2 = \sigma_i^2$) and captures the expectation that the larger means will be associated with larger variances. This results in:

$$w_{ij} \sim N(\lambda_{ij}\mu_i; \lambda_{ij}\sigma_i^2) \tag{4.2}$$

Resultant model

From equation 4.2 it is possible to calculate the distribution of the total inflow weight for each product type j:

$$y_j = \sum_{i=1}^{3} w_{ij}, \tag{4.3}$$

which is normally distributed with mean $\sum_{i=1}^{3} \lambda_{ij}\mu_i$ and variance $\sum_{i=1}^{3} \lambda_{ij}\sigma_i^2$. Now let:

- α_j be the m^3/kg ratio for each food type j;
- β_k be the m^2/m^3 ratio for storage type k (in this case k can be cold or ambient); and
- J_k be the set of products requiring storage type k.

The area of storage of type k required is then given as:

$$A_k = \beta_k \sum_{j \in J_k} \alpha_j \lambda_{ij} y_j, \tag{4.4}$$

which is normally distributed with mean $\beta_k \sum_{j \in J_k} \sum_{i=1}^{3} \alpha_j \mu_i$ and variance $\beta_k \sum_{j \in J_k} \alpha_j^2 \sum_{i=1}^{3} \lambda_{ij}\sigma_i^2$.

Recall that recovery rates (proportion of food fit for consumption) and proportions that need packaging were obtained for each type of product (Section 4.3.2). Now let θ_j be the recovery rate for type j and ϕ_j be the proportion of type j that needs packaging. It is then possible to calculate the requirements for the other side objectives (see page 51) as follows:

- Volume of waste per day $= \sim \sum_{j=1}^{5}(1-\theta_j)z_j x_j$
- Volume of packaging per day $= \sim \sum_{j=1}^{5} \theta_j \phi_j z_j x_j$

- The volume of products to be defaced, sorted and cleaned would rely on unknown constants for each (representing average proportions

Each of these is a sum of Normal distributions and therefore also normally distributed. Also, the i's, j's and k's above can be extended for more product sources, product types and storage types if necessary.

4.4.2 Warehouse Requirements for Non-perishables

Unlike the model for perishable goods, this model will need to keep track of inventory in order to check that there is never more stock on hand than the warehouse can handle. It works on a week by week basis (the rationale for this time period will he explained later). As a simplification, it is assumed that all donations are received at the beginning of the week and that distribution to agencies happens gradually over the week. This can be notated as follows: let s be the weight of products in storage at the beginning of week i, d_i be the weight of products donated to the foodhank during week i and o_i be the amount of products distributed to agencies during week i. Then $s_j = o_{i-1} + d_i$, where d_i is a stochastic variable and o_i is a decision rule and therefore also variable. Each s_i then represent the maximum amount of storage required over week i, as during the week only outflows will occur. Importantly, for simplicity, the remaining shelf-life of the products is not t aken into account. The modelling of inflows and determination of an operating policy will now be discussed, after which performance measures will be addressed as well as an extension to evaluate "good" inventory management practice. In addition, the rationale for a weekly time period will be discussed.

Modelling inflows

Non-perishable inflows come from two sources.

1. *Manufacturers.* These products are donated on a monthly cycle rather than a day-to-day basis. Manufacturers would contact the foodbank when they have products and an arrangement would be made to obtain the food.

2. *Various retailers.* Small volumes of non-perishable products would come on a day to day basis from Robin Good.

Through observation of Table 4.4, there seems to be two types of inflows from manufacturers: fairly consistent small donations and irregular large donations. Donations of less than 20 tons per month are classified as being small. A model was constructed whereby smaller donations would be received every month and larger donations would occur with a probability of 37.5%, estimated from the sample of data.

Smaller donations were modelled using the Gamma distribution, as it appeared that within these donations, the lower range of values were most likely. A best-fit curve was fitted to the data, generating a shape parameter (n,) of 1.2 and a scale parameter (H) of 5.4. Large donations were modelled using a Normal distribution as it seemed equally likely that within this category there could be large or small donations. The observed mean for large months was 50.0 tons, though when modelling this was reduced to 43.5 tons as the mean for small donations was 6.5 tons. As a rough estimate and from observation of the data, it was decided that 95% of the time donations would be between 20 and 80 tons (though again these were decreased by 6.5 tons), resulting in a variance of 225.

If additional manufacturers were to start donating to FBCT, it can be assumed that they will have similar characteristics to the existing manufacturers. Therefore, using Theorem 1, additional manufacturers will result in an increase in shape parameter. Small donations are therefore modelled using G(1 .6a; 4), where a can be adjusted for an increase in manufacturers. As the mean of a Gamma distribution is n'H, a will simply denote a scaling of the mean total from its current level. For ease of adjustment, the ratio of mean to variance for large donations was fixed at a constant. Therefore, by scaling up the mean, the variance would increase accordingly.

Non-perishable inflows from Robin Good averaged approximately 1 ton

manufacturers, a constant weight of 1 ton per week was simply added to the inflovvs from manufacturers.

Theorem 1[Weisstein, b]. If $x_1, x_2, \ldots, x_n$ are independent random variables having a Gamma distribution with parameters (α_1, θ), (α_2, θ), ..., (α_n, θ) then $\sum_{i=1}^{n} x_i$ has a Gamma distribution with parameters $\alpha = \sum_{i=1}^{n} \alpha_i$ and $\theta = \theta$.

Rationale for weekly time period

Originally a monthly time interval was proposed. However, there was a real risk of two or more big donations being received in a single month, which a monthly time interval would not cater for. The model was therefore iterated from week to week. The probability of a big donation was taken as 0.375/4.5 (4.5 weeks per month) and small donations were modelled as G(1.6/4.5, 4).

Outflow

Through workshops with future agencies (see Chapter 6) it became clear that consistent, reliable weekly food volumes were of high importance. In order to determine the amount of outflow each week *(o,),* an outflow factor *(f)* was set at a constant such that *oi* = min(warehouse stock, *frn),* where in is the average non-perishable inflow per week *(f and In* are constants). If = 1, storage space st would follow a random walk process and potentially "blow up". By having *f* greater than 1, warehouse stocks will gradually be depleted after large donations are received.

Performance measures

In order to evaluate storage needs, the weight of stock needs to be converted to volume. A number of different types of non-perishable products were measured for their volume to weight ratio (Table 4.9), however due to a lack of data and for simplicity, non-perishable food types were grouped together to give one volume to weight ratio (the average of the sample obtained). It is possible to simulate the data a large number of times in order to observe how large storage requirements would get, although there are alternatives if storage is full (e.g. temporary storage, negotiating with the supplier to receive the food over a period of time, etc.). It was decided to find the storage levels which were passed 10% of the time, 5% of the time and 1% of the time (termed "cut-off values"). The model was coded in VBA in Excel the code is given in Appendix A.1.1 at the end of the dissertation. The storage would start at 0 at the beginning of week 1. A loop was then run which cycled through 260 weeks (5 years). The storage level required for each week was stored in an array. This array was sorted in ascending order in order to extract the 10%, 5% and 1% levels. This entire process was repeated 100 times and averages and standard errors were obtained for the 10%, 5% and 1% levels. The standard errors gave an indication of how accurate the mean estimates were.

Extension: "Good" inventory management practice

As previously stated, agencies desire a steady supply of food. This will be partially achieved by all perishable food coming through the warehouse.

Previously an agency would receive food from a particular store and therefige variation was high. In future agencies will receive a portion of the total food, which has a much lower variation due to the central limit theorem. It was seen that variation from day to day could be further reduced by implementing different outflow operating policies. The idea is that each day perishable products come in from stores but that this varies. When there is a -low" day, non-perishable products are added in order to try and achieve a more constant level of outflow.

In order to measure the success of an inventory management policy, the standard deviation from day to day was used. Naturally, a lower standard deviation would represent a better operating policy. The performance of any "new" operating policy could be compared to the performance of the previous model (termed "old" operating policy). In order to implement this, the original code was simply manipulated. Now, within each week, a loop was run which simulated day by day perishable inflows (using the distribution already determined), from which decision rules could be deduced. It was important to run the two operating policies (old and new) in parallel — the inflows are random, therefore it would be more accurate to compare the operating policies with the exact same set of inflows rather than to have the possibility of discrepancies in performance as a result of statistical variation. rfhe day by day outflows for the old operating policy were simply the perishable inflows for the previous day added to *o,I7.* The 10%, 5% and 1% levels were then calculated for the new operating policy as before in order to also check the impact on these values. The coding is given in Appendix A.1.2 at the end of the dissertation.

The decision rule that was tested operated by supplementing perishables with non-perishables every time the inflow weight for the day fell below the daily average. The daily average weight of food inflow was calculated by adding the averages for perishable products and non-perishable products. Let Q represent this quantity. Now let *q,* represent the actual inflow weight for day *i.* The model first simulates *q/. If q,* falls below Q, then the weight of non-perishable products distributed is (Q — *qi* falls below Q but the amount of non-perishable product in storage is less than *(Q — O,* then whatever is available in storage is distributed. Finally, if *qi* does not fall below *Q,* no non-perishable products are given.

4.5 Analysis

There are five parts to the analysis.

1. Analysis of the "perishable" model.
2. Analysis of the "non-perishable" model.
3. From the analysis of these two models a simple rule is derived whereby one can input perishable and non-perishable growth and evaluate the warehouse size required. From this, warehouse requirements are estimated for current and future operations.
4. A number of factors that can alter the results of the required warehouse size are addressed.
5. Filially, the specific case of the Philippi warehouse is addressed along with some of the extra complications encountered with it.

4.5.1 Analysis of the "Perishable" Model

An analysis of the warehouse requirements for current inflows (i.e. the com-bined inflows of the three merging operations) is first done, from which a rule is derived that gives the storage requirements per average daily ton of perishable inflow. Sensitivity analysis is then carried out.

Warehouse requirements for current inflows

Table 4.6 shows the results obtained for the current inflows. In each case, the mean and standard deviations are given. Using these and a z-table, values are calculated which will be exceeded, on average, 10%, 5% and 1% of the time (again termed "cut-off" values). The only exception to this is total storage, which was calculated by adding the ambient and cold storage values. Thus, the *.r%* cut-off in this case does not represent the total storage level that will be passed .l· % of the time, but the storage level required to achieve .r% cut-off values for both cold and ambient storage.

It Call be seen that the storage space required for current perishable products is small: 25m2, 18m2 and 431112 for cold, ambient and total storage respectively at the 5% level. The amount of daily waste and packaging to handle is similarly displayed. The amount of sorting can be determined from the daily total as all perishable products need to be sorted. In addition, from the daily inflows the client can roughly determine the amount of daily

Table 4.6: The amount of daily perishable inflow, storage required for perishable products and the amount of daily waste and packaging required when current inflows (without dairy and meat) are used

	Mean	SD	10% cut-off	5% cut-off	1% cut-off
Daily total (m^3)	53.2	5.0	59.6	61.4	64.8
Daily total (tons)	19.5	1.6	21.5	22.1	23.2
Cold storage (m^2)	21.4	2.3	24.4	25.3	26.9
Ambient storage (m^2)	14.0	2.3	17.0	17.9	19.5
Total storage (m^2)			41.5	43.2	46.4
Waste (m^3)	10.0	2.0	12.5	13.2	14.6
Waste (tons)	3.5	0.7	4.4	4.7	5.1
Packaging (m^3)	11.5	2.1	14.2	14.9	16.4
Packaging (tons)	3.9	0.7	4.9	5.2	5.7

cleaning and defacing required. Due to the large number of suppliers, the standard deviation is relatively small, resulting in only minor differences between the mean and cut-off values.

For evaluating storage requirements after growth in inflows, a simple rule was defined for the client whereby a certain amount of storage would be required per average daily tonnage of inflow. This rule was based on the 1% cut-off level. Using current inflows, a daily average of 19.5 tons requires roughly 26.9m2 of cold storage and 46.4m2 of total storage space for the 1% cut-off. This equates to 2.38m2 of storage space for every daily ton of perishable products, and within this 1.38m2 of cold storage for every ton. For this rule, the ratio alp is assumed constant. In reality, this ratio would slightly decrease as more stores are added due to the central limit theorem. However, as there is already a large number of stores contributing to inflows, the decrease in alp would be negligible.

As previously mentioned (Section 4.3.4), currently no dairy and meat products are received from supermarkets. Values for these were added to the current inflows and the simple rule re-evaluated: 1.871112 of storage space would he required for each ton of perishable product, 1.34m2 of which would be for cold storage. The reason for the drop in storage space required (and the small amount of change in cold storage) is that meat and dairy are a lot denser than vegetables, fruit and bakery produce and therefore require less space. it would also be expected for the cold storage figure to go up but this is again offset by the increased density of the products.

Sensitivity

A lot of values input into the model were very uncertain. The sensitivity analysis was focused on the more important of these values. Importance was defined by: 1) the level of uncertainty, and 2) the contribution that changes in this value would have on the end result. Due to the large inioount of data for Feedback, their values were relatively accurate. Estimates for Lions were based on client's judgement and reference to Feedback's data. These estimates were therefore very uncertain. Also, since most of the food volume comes from Lions, its contribution is significant. Attention was therefore placed on Lions' estimates with regard to sensitivity. There were three groups of approximations made for Lions:

1. The proportion of food types;
2. The recovery rates (proportion of food fit for consumption) of different food types; and
3. The weight per store.

For each of these approximation groups, a range of feasible values were estimated, from which two sets of values were chosen: one that would increase values for objectives the most (termed -upper") and one that would decrease values for objectives the most (termed "lower"). Current inflows with dairy and meat from Lions was used as a -base", from which changes in storage space could be evaluated.

The results for the 5% cut-off can be seen in Table 4.7. Each approximation shows the proportional change from the base to the lower and upper sets of values. As the changes are given as proportions, one would expect similar results for the 10% and 1% cases. Results show that the impact of varying food proportions has very little impact on the total amount of storage space required. As recovery rates were very uncertain, these figures varied significantly, which is reflected in the large changes in the amount of waste to be handled. Clearly, there is a very large swing in values for objectives

Table 4.7: Sensitivity analysis showing the proportional change that is incurred from the original values when certain assumptions are modified

	Prop. food type		Recovery rate		Weight/store	
	lower	**upper**	**lower**	**upper**	**lower**	**upper**
Daily total (m^3)	0.91	1.11	0.85	1.09	0.56	1.29
Daily total (tons)	1	1	1	1	0.55	1.30
Cold storage (m^2)	0.76	1.1	0.82	1.12	0.55	1.30
Ambient storage (m^2)	0.64	1.61	0.9	1.03	0.63	1.25
Total storage (m^2)	0.98	1.1	0.89	1.14	0.57	1.28
Waste (m^3)	0.74	1.19	0.62	1.54	0.60	1.26
Waste (tons)	0.73	1.23	0.64	1.49	0.60	1.26
Packaging (m^3)	0.75	1.17	0.83	1.13	0.62	1.25
Packaging (tons)	0.73	1.21	0.83	1.13	0.63	1.25

when the average weight per Lions store is changed. All of these changes can compound each other, which is why results are given as proportions. For example, if the "upper" figures are achieved for "weight per store" awl "recovery rate", daily total tonnage will go up by 1.09* 1.29 = 1.41. However, the values presented are extremes and the likelihood of realizing all the "upper" or "lower" extremes in all approximation groups simultaneously is low.

4.5.2 Analysis of the "Non-Perishable" Model

Varying outflow factors (see Section 4.4.2 and their impact On results are first examined, after which the results of the inventory management rule defined to improve performance are discussed. specific outflow factor is then fixed for sensitivity analysis on non-perishable inflows. Within the sensitivity analysis another simple rule is defined.

Different outflow factors

Table 4.10 in the appendix of this chapter shows the amount of storage space (m2) required for current non-perishable inflows (from Feedback and Robin Good) for different outflow factors and cut-off values. Due to repeating the simulation a large number of times, the standard errors of these estimates are relatively low, resulting in accurate estimates. Figure 4.9 illustrates the storage floor space required for varying outflow factors and cut-off values. It clearly shows how less storage space is required as the outflow factor increases, as would be expected. The curve resembles a hyperbola with an asymptote at an outflow factor of 1 and an asymptote at a storage floor space of between approximately 35 and 60m2, depending on the cut-off used. A daily standard deviation was also recorded for each outflow factor in order to assess how the foodbank performs with regard to distributing consistent daily food volumes. The day to day standard deviation was very similar for all outflow factors, which is somewhat surprising. This is probably due to the small contribution that non-perishable products make to daily weight in comparison to that of the perishable contribution. The average daily outflow is about 20 tons with non-perishables averaging only 1 ton per day. In order to check the validity of the model, an outflow factor of 10 was used. This produced a much higher standard deviation, which confirms that performance decreases with an increasing outflow factor.

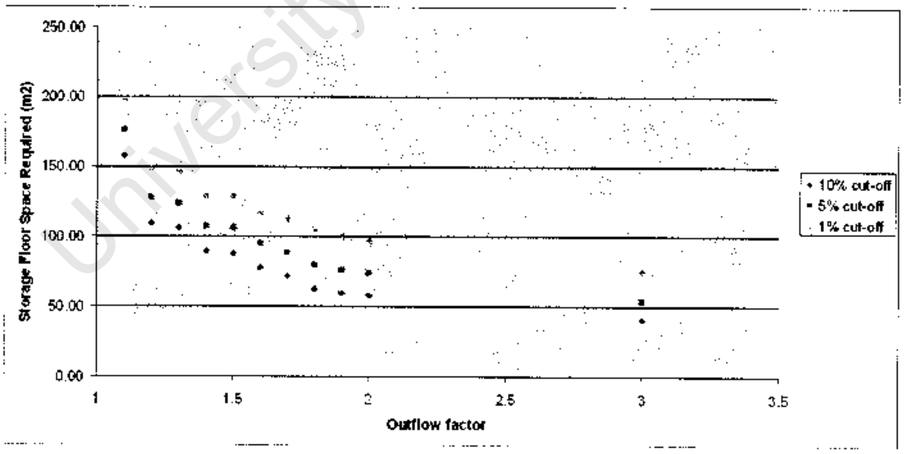


Figure 4.9: The storage floor space required for different outflow factors and cut-off values when current inflows are used.

Inventory management

The inventory management rule (explained in Section 4.4.2) was then run through the model with the results shown in Table 4.10 in the appendix of this chapter. The required storage space was roughly equal to that of when an outflow factor of 1.3 was used. Importantly, performance was markedly improved as the standard deviation lowered from about 1.44 for the outflow factors to 0.89. The inventory management rule was seen as mostly exploratory, therefore it was decided to use an outflow factor of 1.5 for further analysis.

Sensitivity

In keeping with assessing assumptions that are both uncertain and have a large impact on results, only the total mean and probability of large non-perishable donations occurring in a week were changed. From this, another simple rule is developed. Finally, the model simplification of not considering the expiry date of non-perishable product is addressed.

The total mean was varied from half its original value to four times its original value, and the frequency was varied from half of the original frequency to a frequency of 1. The results are shown in Table 4.11 in the appendix of this chapter. Warehouse requirements increase slightly less than if they were directly proportional to inflow means. The relationship between warehouse requirements and the frequency of large donations is a peculiar one (see Figure 4.10). Warehouse requirements seem to reach a peak at around a probability of double the original value and then tail off again. This seems to suggest that warehouse size is more sensitive to the size of large donations than their frequency. This is probably because the former would result in higher peaks whereas the latter would result in more frequent but lower peaks.

It was decided to again develop a simple rule for ease of use for the client. Warehouse requirements are fairly constant for frequencies of between 0.08 n d 0.5 for large donations. As it is unlikely for the frequency to fall outside this range, a constant value of 0.083 (the original frequency) was assumed to be adequate for the rule. The resultant rule is that each average monthly ton of inflow requires 4.54m2 of storage space. Note, however, that this rule should be used with caution. Growth should only be evaluated in terms of an increase in the means of smaller and larger donations and not an increase in the frequency of larger donations. Short-term growth is therefore estimated to be double the means and long-term means are estimated to be 2.5 times current values.

The model simplification of not incorporating shelf-life is now considered. Under current inflows, the 97.5 percentile for large non-perishable donations is 73.5 tons. Using an outflow factor of 1.5, a maximum of 8 tons can be distributed per week. Provided no other product is distributed over this time, this product would take about 2 months to leave the warehouse. If two average large donations were received in two successive weeks, a total of 87 tons would be obtained, which would take about 2.5 months to distribute. From speaking to the Feedback logistics coordinator it seemed that the remaining shelf-life of the product was usually about 3 months. As the values given above are on the "upper end" of the spectrum, the simplification of shelf-life will generally be sound. Occasionally, product will need to leave the warehouse quicker than would be obtained with an outflow factor of 1.5. Results should remain fairly similar as inflows increase because outflows will increase in proportion to the increased inflows.

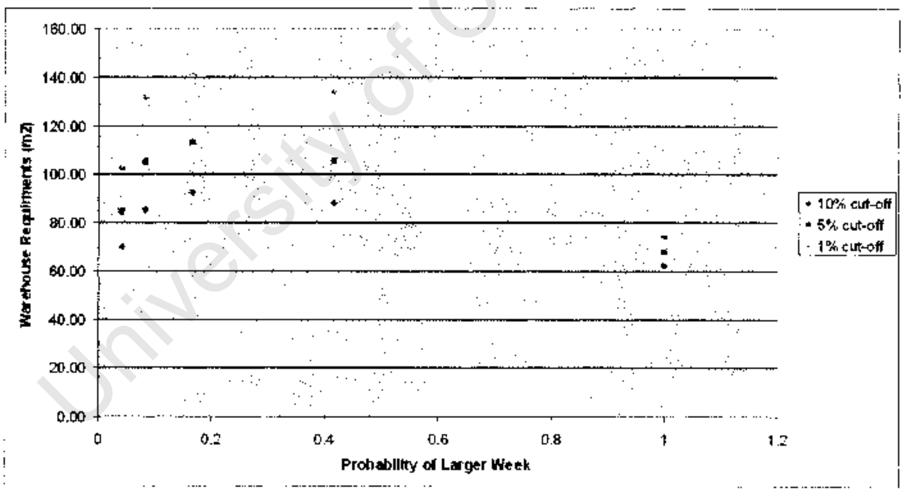


Figure 4.10: Warehouse requirements versus the probability of large donations in a week for 1%, 5% and 10% levels.

4.5.3 Formula for Required Warehouse Size

By combining the two simple rules for perishable and non-perishable inflows (as described in Sections 4.5.1 and 4.5.2), as well as the function of warehouse size against storage floor space, a simple function was determined in order to calculate the amount of warehouse space required. Recall equation 4.1: s = 0.000040)2 + 0.36w;, where s is the amount of storage space and w is the warehouse size. Solving for *w:*

$$w = \frac{\sqrt{s + 810} - 28.5}{0.00632} \tag{4.5}$$

However, s consists of storage space for perishable and non-perishable products. Let t_1 be the average daily tonnage of perishable products and t_2 be the average monthly tonnage of non-perishable products. Then, using the simple rules previously defined for no meat or dairy, $s = 2.38t_1 + 4.54t_2$, and therefore:

$$w = \frac{\sqrt{2.38t_1 + 4.54t_2 + 810} - 28.5}{0.00632}, \tag{4.6}$$

with $1.38t_1 m^2$ of cold storage required. Alternatively, $s = 1.87t_1 + 4.54t_2$ when dairy and meat are collected by the foodbank, with $1.34t_1 m^2$ of cold storage required.

Equation 4.6 allows for quick and easy calculations, which is also beneficial to the client for continued use. Using equation 4.6, current operations (without meat and dairy) would require a warehouse of size 440m2, of which 27m2 is for cold storage. After short-term growth (see Sections 4.5.2 and 4.3.4) warehouse requirements would be 950m2, of which 96m2 is for cold storage, and after long-term growth warehouse requirements would be 1380m2, of which 189m2 is for cold storage. Note that for these growth estimates, additional supermarket chains were assumed to have the same characteristics as the supermarkets supplying Lions. Due to the significant uncertainty about the mean weights from the supermarkets supplying Lions, the warehouse size calculations were done again for the limits of what was considered to be the possible range (150kg, 400kg). This only altered warehouse size by 14% for the lower limit and 7% the upper limit.

Equation ,I.6 was captured in Excel and current inflows with dairy and meat from Lions was used as the starting point. The growth for perishables and non-perishables were left as variables and the percentage growth for each could be input and the resulting warehouse size computed. It was left this way for the client as they would have a better intuition for growth. By simply adjusting the growth figures they can see the impact on warehouse size.

4.5.4 Factors Influencing Warehouse Size Requirements

There are a number of factors (external and internal to the foodbank) that can impact warehouse requirements that have not been considered in the analysis so far. These are now discussed.

External factors

There is no data readily available for these external factors though it is still important to consider how they may influence results.

- *Economic factors.* Changes in food prices may cause people to buy more or less, resulting in more or less waste. Also, increases in food prices may cause companies to manage their stocks more carefully, resulting in less waste.

- *Government regulation/law that impacts On donated food by companies.* Laws that encourage companies to give food could have a significant impact On the amount of food received.

- *The public image of the foodbank.* This would impact on the generosity of suppliers and thus food volumes. This has already been considered through growth predictions.

- *Com,petition from,similar NGO's.* Suppliers may decide to give their excess food to other organizations or individuals.

Internal factors

Internal factors are divided into those that would decrease the warehouse size required and those that would increase the warehouse size required.

- *Factors that would decrease the warehouse size required.* One of the difficulties with this analysis was that, a munber of cont ingency plans are available which are not ideal to utilize, but which would decrease the amount of storage space required. These would be particularly helpful for temporary spikes in inflow. Some Of these include: increasing the rate of turnover of product; minimizing receiving and dispatch areas; installing a mezzanine floor over non-storage areas where non-perishable product could be stored; and, if there is a spike in non-perishable product, to either rent temporary storage or negotiate the delay of the pick-up from the supplier.

- *Factors that would increase the warehouse size required.* These include: having a "buffer stock" for emergencies; supplementing donated food from suppliers with purchased food; using space for initiatives such as a juice machine; and attempting to smooth outflows using decision rules on non-perishable products (Section 4.4.2).

In addition certain internal factors can either increase or decrease the warehouse size required depending on how they are altered. A cut-off level of 1% was used for perishable and non-perishable products. Different levels would alter warehouse requirements. Also, the foodbank can control how active they are in searching for additional food sources. The space available will influence how active they are.

4.5.5 Warehouse Option at Philippi

Soon after the completion of the model an option arose at Philippi for a warehouse with a floor area of 42001112, which was available for short- or long-term lease. It performed very well on all other criteria and the question was asked if it was of good size. Certain characteristics were unique to Philippi which meant that the amount of storage space available needed to be compared with that given from equation 4.1 on page 55. A floor plan was done and individual values checked. Some minor differences were found, however these differences seemed to balance each other out and the storage space estimate from the equation was approximately the same as that from the floor plan.

It was later recommended that the foodbank should lease the Philippi warehouse (see Section 7.2). However, after this recommendation, it was found that half of the space (600m2) could be leased rather than the full 1200m2. As current operations would fit into 6001112, the question was asked as to whether it would be better to simply rent 600m2 of the space until the other 600m2 was needed. This became a very time urgent question therefore a simple and quick analysis was done.

At this stage there was an FBCT director and a funder in place for the warehouse rental. Two options were put forward by the funder:

1. To lease 600m2 for 6 months, during which the other 600m2 could be leased if need be; or

2. To lease 120011.12 for 6 months.

The methodology was to evaluate the expected impact for the two alternatives. Various scenarios were developed for each alternative and their probabilities and outcomes measured. From this, the expected impact for each was calculated. Three issues need consideration in the development of scenarios: the valuation of outcomes, the random variables involved and growth milestones.

Valuation of outcomes

In order to compare the impact of different scenarios, financial values Ivere placed on various issues. These values were obtained through a series of questions to the FBCT director. Below are the issues and their approximated financial values.

- If the 600m2 alternative is taken and someone moves into the adjacent 600m2, the alternative of later expanding into this area is taken from FBCT. It is assumed that in the short to medium term 600m2 will be insufficient, therefore FBCT would ultimately have to move. The cost of moving operations to another warehouse was estimated at 1130,000, based 011 the director's judgement. In addition, there is the risk of finding a less ideal warehouse, which is exacerbated if there is a rush to find this warehouse. This was seen as a major risk as the warehouse found was seen as far superior to a number of alternatives visit ed. The cost of finding a warehouse quickly (within two months) was estimated at R250,000, and if there was no urgency the cost was estimated at R100,000. Finally, products would be turned away because the warehouse is full. This would damage FBCT's reputation (estimated at R20,000).

- There are five offices available for the 1200m2 option but only two for the 600m2 one. The extra office space was valued at R2,500 per mont h.

- The option of building a refrigerated room will essentially be taken away as the amount of capital required is not worth the risk of then having to move. Refrigerated containers would therefore have to be used instead. The cost of not being able to install a refrigerated room was estimated at R10,000.

Random variables

It was seen that there were two random variables, which were each given two possible outcomes for simplicity.

1. The growth of inflows could be either large or small. It was assumed that there was a 60% chance of large growth.

2. If the 600m2 alternative were taken, there is a chance that someone could move into the adjacent space. It was assumed that there was a chance that someone would move in before 6 months were completed.

This results in four possible scenarios for the 6001112 case and two possible scenarios for the 1200m2 case.

Milestones of growth

Two important milestones of growth are relevant.

1. When enough growth has occurred such that the 600m2 alternative is full with racking installed. In order to lift products onto racking, a forklift is required, which costs R10,000 per month.

2. When enough growth has occurred such that the 1200m2 alternative is full on floor level storage. Pallet jacks, at a cost of R1,000 each, Call

The cost of racking was ignored as it was seen that in the long run the same amount of racking would be required and would thus impact all scenarios equally. In addition, racking can be moved from warehouse to warehouse if required. These milestones require taking all dairy and meat and on top of this 30% 40% growth in perishables and non-perishables respectively. If there is slow growth, it is assumed that none of these milestones will be reached within 6 months. If there is fast growth it is assumed that the 30% case will be reached after 3 months and the 40% case after 4 months.

Scenarios

The various scenarios under each alternative are now examined and their outcome equated to financial gains or losses. Importantly, rental for the 600m2 and 1200m2 alternatives are at R20,000 and R40,000 per month respectively.

- *600nt2*

  For all scenarios under the 600m2 case, • forklift is required for 6 months as racking will be required from the beginning. Scenarios are:

  1. *There is large growth and someone moves into the adjacent space.* It is assumed that the adjacent space would be taken after 2 months. The probability of someone moving into the adjacent space from now until the first two months of opening was calculated to be 30% . As per the valuation of outcomes, costs (1) (with a rushed move) and (3) would be inclined.
  2. *There is large growth arid 710-011e 'MOMS into the adjacent space.* Essentially, after two months (when the growth is observed), the other 6001112 will be taken and operation will continue. This allows four months of extra office space.
  3. *Small growth and someone takes the adjacent space.* The probability of taking the adjacent, space is 50%. The cost of a move will need to be factored in as eventually 600m2 will be too small, however the move would not be as rushed and there would therefore not be a huge impact on lost food/reputation.
  4. *Small growth and no on* Effec— tively no extra costs or benefits are incurred as operations continue as usual.

- *1200m2*

  For each scenario there is the benefit of extra offices for 6 months. Scenarios are:

  1. *Big growth.* A forklift is required for 2 months and no extra costs are incurred.
  2. *Small growth.* A forklift will not be required and no extra, costs are incurred.

Results

The expected nett equivalent financial implication (impact) for each alternative does not show overall benefit. For traditional business type problems, a simple profit value could be looked at. Here the goal is rather qualitative (establishing a foodbank to feed the hungry), therefore quantities only have meaning so long as they differ between the two warehouse alternatives. A difference was therefore taken of the expected return of the 600m2 alternative subtracted from the 1200m2 alternative. This was found to be R23,000, therefore the 1200m2 alternative was seen as being superior. It should also be noted that there is less risk attached to the 1200m2 alternative as the return has no variability. Therefore, if the decision-maker is risk averse, which is usually the case, this would further enforce the 1200m2 alternative being the better choice.

Appendix: Warehouse Size

Table 4.8: The details of different categories of food

Category	Examples of types of food	Tonnage per m^3	Storage	Shelf-life (days)	Recovery rate
1	Fresh fruit	0.46	Cold	1	0.5
2	Fresh veg	0.31	Cold	1	0.8
3	Tinned fruit or veg, dried fruit	0.69	Dry	90	1
4	Bread, pastries, potatoes, sandwiches	0.25	Dry	1	0.95
5	Rice, pasta, maize	0.80	Dry	60	1
6	Cereal	0.29	Dry	60	1
7	Dairy	0.57	Cold	1	0.9
8	Long life milk, Powdered milk	0.83	Dry	30	1
9	Meat, fish	0.40	Frozen or cold	30	0.9
10	Tinned beans, tinned tuna, tinned meatballs	0.70	Dry	90	1
11	Sweets, spreads, tea, coffee, juice, cooking oil	0.60	Dry	90	1
12	All cooked food, Woolies prepared food	0.80	Not stored	1	0.8

Table 4.9: Data collected from a sample of food products

Category of food	Product	Volume (cm^3)	Weight (kg)	ton/m3
1	mixed veg 1	2268	0.6	0.26
	mixed veg 2	1728	0.5	0.29
2	banana box	3808	1.7	0.45
	naartjie box	6380	3	0.47
3	tinned apricot	596	0.41	0.69
4	mixed frozen veg	1954	1	0.51
5	albany brown bread	3312	0.8	0.24
	blue ribbon white bread	2673	0.7	0.26
6	spaghetti packet	666	0.5	0.75
	rice	2470	2	0.81
	maize meal	2950	2.5	0.85
7	Rice crispies	5040	0.4	0.08
	Wheetbix	3290	0.9	0.27
	jungle oats	2363	1	0.42
	muesli	1995	0.75	0.38
8	2l milk	2534	2	0.79
	big yoghurt	2197	1	0.46
	set of small yoghurts	1269	0.6	0.47
9	long life milk	7559	6.2	0.82
	powdered milk (roughly equal to maize meal)	2950	2.5	0.85
10	steak	3402	1.90	0.56
	chicken	3698	1.60	0.43
	I & J Frozen fish 1	1435	0.5	0.35
	I & J Frozen fish 2	1466	0.4	0.27
11	baked beans	596	0.42	0.70
12	Box of rolo's	3150	2.08	0.66
	sugar	6082	5	0.82
	peanut butter	1450	0.81	0.56
	bovril	456	0.25	0.55
	biscuits	1032	0.2	0.19
	juice	2534	2	0.79

Table 4.10: The square metrage of floor space surpassed for different percentages of time when different outflow factors and the inventory management rule are used with current inflows. "Performance" denotes the total standard deviation in inflows from day to day as well as the standard error of this standard deviation.

	10%		5%		1%		Performance	
Outflow factor	**Mean**	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**	**Std. dev.**	**Std. dev. std. error**
1.1	157.41	10.12	176.46	10.61	198.08	11.06	1.13	0.01
1.2	109.66	4.30	128.04	4.70	149.91	5.02	1.13	0.01
1.3	106.04	5.48	123.39	5.68	146.58	5.83	1.45	0.01
1.4	89.19	4.17	107.42	4.64	129.03	5.07	1.43	0.01
1.5	88.01	3.67	106.36	3.98	129.86	4.30	1.44	0.01
1.6	77.90	3.57	95.08	4.05	117.58	4.49	1.43	0.01
1.7	71.44	2.97	88.57	3.44	113.15	3.89	1.45	0.01
1.8	62.32	2.16	79.66	2.67	104.44	3.16	1.44	0.01
1.9	59.69	2.44	76.26	2.87	100.50	3.45	1.45	0.01
2	57.86	1.72	73.88	2.15	97.52	2.67	1.45	0.01
3	40.43	0.84	53.93	0.96	75.41	1.56	1.49	0.02
	105.10	6.55	123.32	6.93	145.59	7.37	0.89	0.01

Table 4.11: The square metrage of floor space surpassed for different percentages of time when the "overall mean" and "frequency of larger weeks" is changed from current inflows.

	0.1		**0.05**		**0.01**	
	Mean	**Std. error**	**Mean**	**Std. error**	**Mean**	**Std. error**
Original	85.46	3.89	105.27	4.35	132.05	4.75
Halve mean	45.68	2.09	55.45	2.33	68.70	2.52
Double mean	165.00	6.83	199.36	7.42	247.41	8.31
4x mean	294.76	10.07	361.36	11.45	455.87	13.04
Halve freq.	69.99	3.75	84.25	4.06	102.89	4.38
Double freq.	92.60	3.10	113.12	3.63	141.42	3.99
5x freq	88.05	1.94	105.59	2.43	133.91	2.99
Every week big	62.42	0.16	67.45	0.20	74.78	0.28
5x freq. + 2x mean	157.77	2.90	191.52	4.67	243.72	6.17

Chapter 5

Warehouse Location

The basic methodology for tackling the problem is first put forward. From this, the necessary data becomes apparent. The available data is then explained, after which data analysis is carried out in order to extract the required information from the available data. The warehouse location model is subsequently described and finally analysis is canied out both on the location problem as well as related areas.

5.1 Methodology

The following would be required:

- Supplier and agency locations;
- A system for mapping these locations; and
- A method for calculating the travel cost between two locations.

An approach similar to that of Whiteman [1964b] was then used: an algorithm was developed that would calculate the total transportation cost depending on the coordinates of the warehouse. Necessary information (e.g. supplier and agency locations) was input into Microsoft Excel and the algorithm coded in VBA. By running a macro in VBA, a map of warehouse coordinates was generated with the associated cost for each. From this, a 3-dimensional graph of transportation cost was calculated as per the coordinates of the warehouse, from which the minimum could be determined and comparisons between locations made.

5.2 Data Gathering

The methodology for estimating travel costs is first presented. The mapping system is then discussed, after which the data on suppliers and agencies is explained.

5.2.1 Method for Calculating Travel Cost

The distance travelled between two points is used as a basis for calculating travel cost. For simplicity, the Euclidean distance between points is used. This distance is then multiplied by sonic "air to road" conversion factor that would measure how much longer road distances between two points are than air distances. A factor of about 1.3 was recommended as a general heuristic [de Jong, 2008]. This value was also used by Whiteman [1964b] in a similar problem.

In addition, road network data for the greater Cape Town area was obtained[N1ans, 2008] and permission obtained from the City of Cape Town for its use. Although this data was not directly used for calculating travel distances, it was indirectly used, as will be later explained.

5.2.2 Mapping System

Some form of map with coordinates was required. The number of supplier and agency locations ranged from about 450 for the current set-up to an estimated 650 for the future set-up. In order to simplify the algorithm for calculating travel cost and the data requirements for it, it was decided to classify suppliers and agencies according to designated "regions". This would also shorten computational time, as fewer destinations would be required for truck routes. This was seen as important as the complexity of routing problems grows non-linearly with an increasing number of delivery points. Compounding this is the desire to generate a "cost map" and to run a sensitivity analysis, both of which require running the model a large number of times. As will be shown in Section 5.2.4, future predictions for agency locations were done using a poverty map, which was constructed using -main place" levels, as defined by StatsSA [StatsSA, 2001]. There are 42 "main place" levels in the Cape Town area of operation, which were used as a proxy for the "regions". A shape file of the Western Cape with main places was obtained{Mans, 2008] (see Figure 5.4 in the appendix of this chapter). All spatial analysis was carried out using AccuGlobe, which is GIS open source software.

5.2.3 Suppliers

Suppliers could be split into those that supply perishables (typically retailers) and those that supply non-perishables (typically manufacturers). It was decided to omit manufacturers from the analysis. As they give much larger volumes than regular suppliers do, large trucks would have to be hired to collect this product rather than fitting it into a typical foodbank truck route. The major cost would be the fixed cost of hiring the truck for a day, therefore the variable cost incurred through travelling further for a different warehouse location would be minimal. These costs would also be negligible in comparison to the other logistical costs as manufacturers are visited far less regularly than other suppliers are. A list of current and future supplier locations is now given.

Current

Feedback had records on the weights and location of each of its suppliers. Lions was supplied from a supermarket chain, for which locations were obtained via their website. No detailed information was available for Robin Good though Feedback's suppliers were simply scaled up by roughly 10% to cater for this. This resulted in a total of 92 suppliers, which would need to be visited daily.

Future

The long-term growth estimated in Section 4.3.4 is again assumed. Supermarkets were therefore scaled up by an additional 150% to give a total of 191 suppliers. The number of suppliers in each region was then calculated by scaling up the number of supermarkets in that region by 150%.

5.2.4 Beneficiary Agencies

Again, this is split into current and future locations.

Current

A list of current agencies, with their addresses, was obtained from Lions and Feedback. Again, Feedback's agencies were scaled up to compensate for Robin Good. This resulted in 360 agencies.

Future

Through research into the allocation model (Chapter 6) it was noted that the foodbank would ideally like to allocate food in the Cape Town area according to the level of poverty in each region. It was therefore decided to develop a poverty map and to assume perfect correlation between the poverty share per region (i.e. what proportion of the total poverty is in this region) and the number of agencies in the region. The 2001 Census data was available, for which poverty measures could be used. It was confirmed that although this data is not recent, the change in poverty share distribution since then would be minimal; therefore the data would be adequate [Mans, 2008]. Similarly, this data would be adequate for estimating what the poverty distribution would look like in the long-term (5 to 10 years). It was estimated that growth would result in an increase of 25% in the number of agencies, as a substantial portion of growth in weight would be aimed at increasing the weight allocated to each agency. This resulted in 450 agencies.

5.3 Spatial Data Analysis

In order to proceed with creating a model that would estimate transportation cost, the following was required:

- Current suppliers and agencies would need to be classified by region;
- The poverty level for each region would be required to estimate the number of future agencies;
- The geographical scope of operation would need to be defined; and
- The coordinates of the centres of regions would need to be determined as well as their radii (By assuming that regions are circular, a measure for travel distance between agencies within a region can be determined using the radius of the region.).

Each of these is now discussed in the order given above.

5.3.1 Classification of Current Suppliers and Agencies

Addresses were z-ivailable for all suppliers and agencies, therefore each was assigned to a region with the aid of a personal GPS. The only difficulty found was that of the -Cape Town" main place. This main place can be seen in Figure 5.5 in the appendix of this chapter. As can be seen, a large

Table 5.1: Poverty threshold by household size

Household Size	2001 R per month
1	587
2	773
3	1,028
4	1,290
5	1,541
6	1,806
7	2,054
8+	2,503

area of land is covered and this is over disjoint regions. This main place also has the largest number of suppliers, making it an important region to model accurately. This region was therefore split up into five smaller regions and suppliers allocated accordingly. This was not done for future agencies as future predictions relied on poverty data that was only available by main place level.

5.3.2 Poverty map

The poverty level per main place was defined as the number of people living below the Nlinimum Living Level (NILL), as defined by the Bureau of Market Research [Bureau of Market Research, 1996]. This MLL is given as a required monthly income per household size. If the household has an income less than this, the members of the household are said to be in poverty. Table 5.1 shows the income level per household size.

Data on yearly household income for different household sizes was obtained from the Census 2001 data from Stats SA. Importantly, the Minimum Living Level data and census data are both defined for 2001 to prevent inflationary differences. This data was given for 14 annual income categories, which are shown in Table 5.6 in the appendix of this chapter. Each income category represented had its own table of data, resulting in 14 tables. Each of these tables had as its rows the main places of the Western Cape and as its columns the household size. Each cell gave the number of people for a given household size and main place. The monthly N1LL's were converted into yearly MLL's by simply multiplying by 12 so that these could be compared with the income categories given by Stats SA. Unfortunately, different

Table 5.2: Proportion of people in poverty per household size and income category. Income categories 7 to 14 are excluded as all household sizes in these income categories had 0% poverty.

HH Size	**Income Category**					
	1	**2**	**3**	**4**	**5**	**6**
1	1	1	0.47	0	0	0
2	1	1	0.93	0	0	0
3	1	1	1	0.29	0	0
4	1	1	1	0.61	0	0
5	1	1	1	0.93	0	0
6	1	1	1	1	0.13	0
7	1	1	1	1	0.28	0
8 +	1	1	1	1	0.56	0

income categories could not be asked for, which resulted in MLL's inside income categories. For simplicity, a Uniform distribution of people over each income category was assumed. Therefore, for example, if the income category for a particular household size was R0 111000 and the MLL was R400, then 40%) of the population in this category would be classified as being in poverty.

The proportion of people in poverty per household size and income category is given in Table 5.2. The number of poor people in each region was calculated as follows: let *..ruk* be the number of households in region *i,* income category *j* and of household size *k;* let *pjk* be the proportion of poor people hi income category *j* and household size *k;* and let zi be the number of poor people in region *i*. Then zi = j *k.rukpjk*

5.3.3 Geographical Scope of Operation

Inherent in the poverty map are statistics of population and the number of poor people per region. Using this, as well as the boundaries of the future Cape Winelands District FoodBank, an estimated area of operation was defined (at the time of research a foodbank was being developed for the Cape Winelands District, whose geographical boundaries were clearly defined). FBCrs area of operation is given by Figure 5.6 in the appendix of this chapter.

5.3.4 Centres of Regions and Radii

Once the geographical scope was defined, the coordinates of the centre point and the radius of each region were estimated through observation (AccuGlobe had a measuring tool to assist with radius approximations). Radii, and particularly midpoints, were adjusted according to where human activity was concentrated within a region (which was approximated using the road network shown in Figure 5.7 in the appendix of this chapter), as clearly this would influence collection and delivery locations. This was most notable for the -Cape Town" main place/region as this encompassed Table Nlountain.

5.4 Description of Warehouse Location Model

A large amount of flexibility was aimed for in the model, such that a wide range of parameters (including those relating to the secondary objectives defined in Sect ion 2.4) could be adjust ed to view t heir impact on total cost . This aided either in sensitivity analysis of the parameters or in deciding what to set t hese parameters at. Major logistical cost contributors were identified through working with FBCT's logistical coordinator and were categorized as either fixed (e.g. logistical management) or variable (e.g. petrol costs, driver salaries and capital expenditure on vehicles). It was decided only to model variable costs. As all variable costs were seen as being roughly directly proportional to distance travelled, only petrol costs (which were assumed directly proportional to distance travelled) were modelled. Section 5.5.7 then addresses how the total variable cost will increase by taking into account the other variable costs, though importantly relative differences in variable costs will remain unchanged.

An overview of the model is first given, after which the details of the procedure are explained. Generally, simplicity and accuracy with respect to actual operations are aimed for (routing at FBCT is currently done predominantly through human intuition) in the algorithm rather than efficiency in attempting to minimize travel distance (through advanced algorithms). Cost improvements could later be obtained through using better routing algorithms. Importantly, these changes would not significantly alter the optimal warehouse location as better routing algorithms would decrease total cost but would have little impact on relative cost differences between different warehouse locations.

5.4.1 Overview of Model

For the purposes of warehouse location supplier and agency routes were calculated separately. The result would be a slight over-estimation Of total cost, incurred through extra travelling to the warehouse; however the relative difference of total cost between location points should remain the same. The algorithm is therefore identical for suppliers and agencies; the only difference being that transportation costs to visit all suppliers are multiplied by six to obtain weekly cost as suppliers are visited six days of the week whereas agencies are visited once a week. In explaining the algorithm, reference will be made to agencies, though the same applies for suppliers. The total logistical cost is calculated as follows.

1. The total dist ance covered is first estimated. This is divided into two parts:

   (a) *Calculating the distance covered by "region trips".* A *region trip* is defined as a truck delivering its entire product to one region before returning to the warehouse. The algorithm seeks to first construct as many *region trips* to each of the regions as possible before constructing routes of agencies over different regions. This is roughly how routing currently occurs at FBCT. The rationale is that agencies in the same region are usually closer to each other than to agencies in other regions. The maximum possible number of *region trips* to each region is therefore calculated and nmltiplied by the distance per trip to that region. This is then summed over all regions to give the total distance covered.

   (b) *Use the Clarke-Wright routing algorithmClarke arid Wright /1962] to calculate the remaining distance.* The Clarke-Wright routing algorithm would subsequently be used to establish truck routes for the remaining agencies.

2. Estimates are placed on travel time per kin, fuel consmnption, fuel cost, etc. Then, using the total distance covered, the total fuel cost can be estimated as well as the number of trucks required.

5.4.2 Detailed Description of Procedure

A list of starting assumptions and constants is first required. These can be found in the appendix of this chapter, along with other relevant symbols that are later defined. This section then systematically describes the model.

First, the distance covered by *region trips* is calculated, after which the remaining distance is calculated with the Clarke-Wright algorithm. The total transportation cost is subsequently determined. Within the calculation of distance covered by *region trips,* there is a more intricate calculation for the distance between agencies in the same region, which is explained at the end of this section. In addition, a pick-up radius was incorporated, whereby agencies within a certain radius of the warehouse would collect from it. The details of how this was calculated is given in the appendix of this chapter. The code for the whole algorithm is given in the appendix at the end of the dissertation.

Distance covered by region trips

Note: Please refer to the appendix of this chapter for definitions of symbols.
The following are calculated:

1. *The road distance from the warehouse to the midpoint of each region i (w_i)*

   This is equal to the Euclidean distance multiplied by the "air to road factor" ϕ: For each region i, $w_i = \phi\sqrt{(x_0 - x_i)^2 + (y_0 - y_i)^2}$.

2. *The average distance between agencies in a specific region i (v_i)*

   See Section "Distance between agencies in same region" on page 105 for details on how this is calculated.

3. *The average number of agencies visited per trip (μ)*

   There are two aspects to this: (1) truck capacity and (2) time available per day. With regard to the former, the average weight at each agency is calculated as

   $$\lambda = \frac{\beta}{\alpha \sum_{i=1}^{n} z_i},$$

   where $\sum_{i=1}^{n} z_i$ is the total number of agencies. The average number of agencies visited per trip is then calculated as:

   $$d/\lambda. \tag{5.1}$$

   With regard to the second, a constraint is imposed that states that the amount of working time per day (h) cannot be surpassed by the operations in a day, which are represented as loading the truck in the morning, travelling from the warehouse to the first agency, travelling in-between agencies, travelling from the last agency to the warehouse and spending time off-loading at the various agencies. This is given as:

$$h \geq l + e(2W + V(\mu - 1)) + g\mu \tag{5.2}$$

where $W = \frac{\sum_{i=1}^{n} w_i z_i}{\sum_{i=1}^{n} z_i}$ and represents the average distance from the warehouse to the first and last agency, and $V = \frac{\sum_{i=1}^{n} v_i z_i}{\sum_{i=1}^{n} z_i}$ and represents the average distance in-between agencies, each of which is a weighted sum depending on the number of agencies in the region. Rearranging:

$$\mu \leq \frac{e(V - 2W) + h - l}{g + Ve} \tag{5.3}$$

Assuming it is optimal to deliver to as many agencies as possible on one route, the above inequality changes to an equality where the right hand side is rounded down, as a fraction of an agency cannot be visited. Overall, this results in μ being the minimum of $\frac{e(V-2W)+h-l}{g+Ve}$ from equation 5.3 and d/λ from equation 5.1.

4. *The number of* region trips *to each region i (U_i) as well as the number of left over agencies in region i (Z_i)*

   $U_i = z_i/\mu$, rounded down. Z_i is then given as $z_i - \mu U_i$.

5. *The average region trip length to each region i (T_i)*

   It was decided to simply use the Euclidean distance from the warehouse to the midpoint of each region as the first and last agencies of a trip. An estimate for the total distance travelled to and from a region i was therefore given as: $2w_i + (\mu - 1)v_i$.

6. *Total region trip distance*

   This is given as $\sum_{i=1}^{n} U_i T_i$.

In the above calculations, averages were often used where in reality the values are random variables (e.g. μ, T_i, etc.). It was thought that this would not significantly impact results due to the large number of variables and the central limit theorem, and thus that the total distance would be roughly preserved.

Clarke-Wright algorithm

The distance required to visit the remaining agencies is calculated using the Clarke-Wright algorithm. Each region is viewed as a separate customer located at the midpoint of the region with demand equal to the number of agencies in that region. The Clarke-Wright method is then applied as usual, travelling between midpoints of regions and meeting demands (numbers of agencies) at each of these midpoints. This would take care of all travelling between regions. The in-between distances of agencies at the same region are then added afterwards depending on the number at each region. A pseudocode for the Clarke-Wright algorithm is given in the appendix at the end of the dissertation.

Total transportation cost

The total distance covered (T) is then calculated as the sum of the total distance from regional trips and that covered by the Clarke-Wright algorithm with the in-between distances added afterwards. The financial cost of this distance is then given as $\frac{Tp}{f}$, therefore the weekly financial cost is $\frac{Tp\alpha}{f}$.

Distance between agencies in same region

Assume, for simplicity, that the region is circular with radius r and that there are θ agencies in the region. If agencies are evenly spread throughout the region, each would take up $\frac{\pi r^2}{\theta}$ amount of space. If each agency is represented as a circle with radius η, then $\eta^2 = \rho_1\rho_2\frac{r^2}{\theta}$; where ρ_1 and ρ_2 are constants between 0 and 1 to compensate respectively for (1) smaller circles not fitting exactly into bigger circles and (2) there being clusters of agencies rather than them being perfectly spread out over the region.

Numerical solutions exist for ρ_1: for a given number n of smaller circles fitting "exactly" into a bigger circle, ρ_1 gives the proportion of space that the smaller circles take up [Specht]. An estimate of 0.75 for ρ_1 was decided upon, which equates to an n of 24. As most "regions" have between 5 and 20 agencies, the "true" value for ρ_1 will almost certainly always be within 0.1 of this estimate (as this corresponds to $3 < n < 400$ [Specht]) and usually within 0.03 (this corresponds roughly to $12 < n < 36$ [Specht]). Through human judgement, ρ_2 was estimated to be 0.7. This results in $\eta = 0.72\frac{r}{\sqrt{\theta}}$, where two agencies would be 2η apart.

5.5 Analysis

The constants assumed for the analysis are first discussed, followed by the results for warehouse location and relevant sensitivity analysis. Related areas of analysis are then explained, including trucking requirements, the number of deliveries per week and pick-up radius. In addition, consideration is given as to how transportation costs, which are estimated by the model, can be adjusted to include other logistical costs in order to give a sense of the magnitude of total costs incurred.

5.5.1 Constants Assumed

Table 5.3 gives the values assmned for the constants that have not yet been dealt with. This information came predominantly from the FBCT director and FBCT logistical coordinator. This resulted in each truck visiting a maximum of either 29 agencies or 16 suppliers per day, which was in accordance with daily Feedback routes given by their logistical coordinator.

Table 5.3: Values assumed for outstanding constant

Constant	Value assumed
d	2 tons
f	7.75km per litre
p	R7.75 per litre
e	1.5 minutes per km
h	480 minutes
g	10 minutes for agencies and 20 minutes for suppliers
l	30 minutes
W	12.5 km for agencies and 22.0 km for suppliers
V	1.3 km for agencies and 2.9 km for suppliers

5.5.2 Results

The total transportation cost was systematically calculated for each grid point over a grid of (x, y) coordinates. These coordinates went up in increments of 1 kilometre. (33 x 26) grid points were sampled, covering a rectangular area from Noordhoek in the South-West to Brackenfell in the North-East, which can be seen in Figure 5.8 in the appendix of this chapter. The resulting grid of costs was generated for (1) current agencies and suppliers and (2) future agencies and suppliers. Due to the approximations of the model the proximity of grid points, any interpolation beyond the grid points would add little further value.

Figure. 5.9 in the appendix of this chapter shows a scatter plot of cost for the current set-up. The minimum for "current" was R22,500 monthly while the minimum for "future" was R48,500. The minimum for "future" was 6 kilometres East of the "current" minimum). The reason for the large difference in minimum cost estimates between "current" and -future" is partly due to increased operations, though also due to increased weights per store in the future (it is anticipated that proportionally more supermarkets will be visited in the future). At the same time the average truck size was left constant (at 2 tons), meaning that the number of suppliers or agencies per trip dropped substantially, resulting in more trips being required. In reality, larger trucks could be purchased in the future, which would lower transportation costs.

The reason for the large difference between current and future ideal location is as follows: "Poverty is centred on two *areas:*

1. The Cape Town main place (22%) (unfortunately more precise data is unavailable to further break up this large region)

2. The main places of Mitchell's Plain, Guguletu, Khayelitsha, Nyanga, Crossroads and Langa (61%), which are highlighted in Figure 5.10 in the appendix of this chapter.

Currently 4:3% of agencies are in the Cape Town main place while only 36% are in area 2 above. The Cape Town main place is to the \Vest while *area* 2 is to the East. As the geographical agency spread shifts from the current set-up to one that closer reflects actual poverty distribution, so the ideal warehouse location shifts toward the East."

Taking into account the approximations of the model and the fact that it is highly unlikely to be able to have a warehouse at the exact coordinates of the -minimum" as predicted by the model, it was decided that total costs within 5% of the minimum would be seen as the "ideal" zone. Consideration would then need to be given to the extra cost incurred for warehouses outside of this zone. If the cost function is assumed circular, a 7 kilometre radius for "current" and a 5 kilometre radius for "future" would result. This resembles a relatively large area and is similar to the results from Whiteman [19644 where it was stated that "The areas of minimal cost are fairly large and flat" . This resembles a quadratic function where the slope increases as the coordinates move further away from the minimum or maximum. This would he expected as the cost function is largely a function of the sum of squared distances from the various regions, which would produce a quadratic function.

It was therefore decided to use a weighted sum of the current and future costs generated from their respective macros in order to give an "overall ideal". "Future" costs were first scaled so that the minimum was equal to the 'current" minimum. "Current" and -future" costs were then directly comparable so that they could be scaled according to their perceived importance. There were a number of reasons for placing more emphasis on the ideal future location:

- The goal is to lease a warehouse that will be ideal for the long-term as the cost of moving operations is substantial (see Section 4.5.5).
- The transition from the ciffrent agency profile to the -future" agency profile is expected to happen quickly (within two years), due to the transition from initially merging three organizations and their agencies to becoming a much more "Cape Town representative" foodbank.
- The 5% cost radius is smaller for "future", indicating that differences in location are more sensitive for this case, as well as the total transportation costs being higher due to increased operations. Therefore differences between actual and the ideal future locations are more costly than differences between the actual and ideal cinTent locations.

A weight of 2 was therefore placed on "future" costs and a weight of 1 on -current" costs. The "overall" minimum was then given as 1122,700 at (-40; -62), the same location of the future ideal, with a 5% radius of 6 kilometres. Intuitively, the overall ideal coordinates would have been expected to be a weighted sum of the current and future coordinates, giving (-42; -62). The difference is partly because the slope of the current cost map was more gradual East of its ideal, but also due to minor variations in the cost estimates.

In order to visualize all of this in a more practical sense, Google Earth was used. Figure 5.1 shows the "Current" ideal, "Future" ideal (which is also the "Overall" ideal) and "Philippi warehouse" (to be discussed in the next paragraph) locations. From Figure 5.1 it can be observed that there are two major highway intersections near the overall ideal, one 4 kilometres to the North-West and one 6 kilometres to the South-East (the border of the 5% zone). Ideally the warehouse should be situated near a major intersection for ease of accessibility to different areas. Taking into account the road structure, a new rough ideal zone can thus be classified as the polygon that the N2 and AI7 make around the overall ideal location, with the warehouse preferably near one of these intersection points. In addition this area could extend a little past the intersection point to the North-West. Also to be considered is that more industrial land is available here and that property, and therefore warehouse rentals, would be cheaper in this polygon compared to the current ideal in Rondebosch East, a residential area. The overall petrol costs associated with a warehouse theoretically at the coordinates of these two intersections was R22,900 per month for the West location and 1123,300 for the East location. There are therefore no major differences between the two, though the former would be preferred.

Once the analysis into ideal location was complete, the option at Philippi came up. The cost estimate at the Philippi warehouse coordinates were then computed -t.nd compared to the "curmit", -future" and "overall" minimums. It was found to be 5.4%, 3.6% and 3.7% higher than these respectively. In addition, the Philippi warehouse is near the South-East intersection.

5.5.3 Sensitivity Analysis

A number of assumptions have been made through the modelling process, predominantly around supplier and agency locations (Sections 5.2.3 and 5.2.4 respectively). Values for constants were also assumed (Section 5.5.1). These can be broken into:

1. Assumptions that alter total cost but not relative differences between locations, such as air to road factor (0), petrol price; and

2. Assumptions that alter relative differences, such as the location of suppliers and agencies and the problem structure.

In evaluating warehouse location, attention will be placed on the second set of assumptions. With regard to the location of suppliers and agencies, the -current" set-up is fairly certain; and although there is uncertainty around the future set-up, this is minor. The major uncertainty for the second set of assumptions is around problem structure and is typical of "soft" OR. An example of one such uncertainty is the possibility of utilizing the existing routes of franchise supermarkets. Currently, every day trucks leave

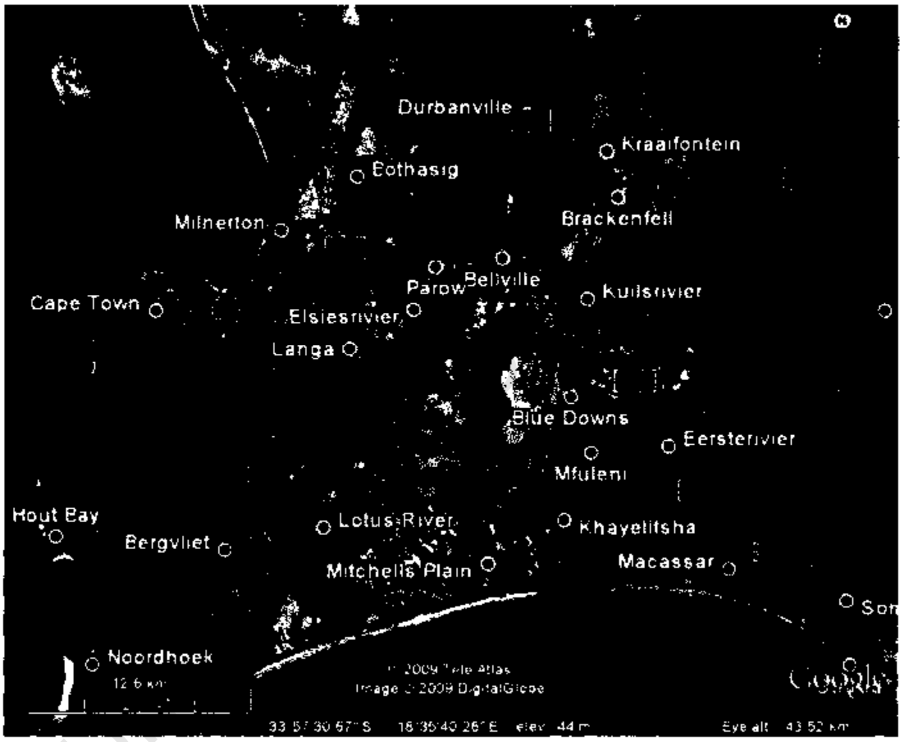


Figure 5.1: Google Earth image of the Cape Town area with the ideal current, future and Philippi sites highlighted

the distribution centre (DC) of franchise supermarkets filled with product, distribute it and then come back empty. It has been suggested that when the delivery trucks drop off food at stores, they simultaneously pick up their stores' -waste". The foodbank could then simply send large trucks to the DC's every day to pick up the food rather than having to go to every supermarket. This would clearly have a large impact and saving on logistics, though it would change the structure of the problem by merging a number of suppliers into one collection point at a different location to the supermarkets. If this strategy were to be implemented, transportation costs for visiting suppliers would drop and the warehouse would therefore be better placed closer to agencies.

The use of depots for delivery is another suggestion that was put forward that would alter the structure of the problem. This proposal is to send food to strategically situated depots, from which a number of agencies can collect, rather than delivering directly to them or having them collect from the warehouse. This policy would shift the location of the warehouse closer to suppliers if implemented. As an extension, some sort of Bayesian approach could be used whereby results Of different set-ups are analysed along with their probabilities, though this is difficult and time consuming to model.

The coordinates of the warehouse were then set to those of Philippi and supplier and agency locations set according to the "current" set-up. The trucking requirements were assessed, after which the number of deliveries

transportation costs. Although these issues are not relevant to the problem of warehouse location they were identified as secondary objectives in Section 2.4. Even though the current set-up was used, the same results can he expected for other set-ups. The details and results of these considerations are now explained in the ensuing sections.

5.5.4 Trucking requirements

It is clear that the more agencies or suppliers that are visited per trip, the lower overall logistical costs will be, as fewer trips are required back to the warehouse to re-load or off--load. Therefore, the optimal truck size will be to have a truck that is just big enough to be out on the road for a full day (cold chain preservation was said to not be an issue by FBCT staff as refrigerated trucks would be acquired for product that require this). However, through discussions with staff at FBCT the maximum truck size for delivery to agencies was said to be 2.5 tons (hue to sizes larger than this being too cumbersome for the areas visited. In addition, room should be allowed for statistical variation. Also, average weights/volumes differ per agency or supplier therefore a range of truck sizes may he optimal.

The timing constraint (see page 103) allowed for a maximum of 29 agencies or 16 suppliers to be visited per day under the current set-up (see page 106). The truck load constraint allowed for 10 agencies or 15 suppliers to be visited per day (see page 103). Taking into consideration that suppliers and agencies could be mixed on a route and that multiple trips could occur on the same day by the same truck, it was calculated that one truck could either visit 15 suppliers and 2 agencies per day (truck capacity would allow for 15 suppliers with 1/16 of a day left for agencies, which equates to approximately 2 extra agencies) or 20 agencies per day (by factoring in travel time back to the warehouse and load time, it was calculated that 2 trips of 10 agencies each could roughly be done per day). There are 92 suppliers that need to be visited per day and 60 agencies per day, which results in 8.52 2-ton trucks being required (rounded to 9). Truck requirements would decrease through improved routing or further mixing of suppliers and agencies along the same route. However there should probably also be an extra truck on standby. This results in 9 or 10 trucks being required.

These calculations are quick and rough in order to establish the order magnitude of the logistics requirements. The actual problem is much more complex and would consist of assessing actual routes and the current fleet of vehicles. Importantly, the assumption of an homogeneous set of vehicles would affect the day-to-day routing specifics and total cost incurred, though not the relative costs between locations and hence the optimal warehouse location.

5.5.5 Deliveries per week

The number of deliveries to agencies per week was compared with the increase in cost incurred to the foodbank. Intuitively, it may seem that a doubling of the number of deliveries per week would result in a doubling of the cost in supplying them; however as deliveries per week increase so volume per delivery decreases and therefore more agencies can be supplied per trip, resulting in increased efficiencies (provided there is sufficient time remaining in the day to increase the number of delivery points). Table 5.7 in the appendix of this chapter shows the cost of delivering to agencies for different numbers of deliveries per week (including the increase in driver salaries and vehicle expenditure). Also, the number of agencies who need to be supplied per trip is given, as this could become a constraining factor. Figure 5.2 plots the total weekly cost, divided by the number of deliveries per week, against the number of deliveries per week. This Figure shows that as the number of deliveries per week increases, so the cost per delivery decreases.

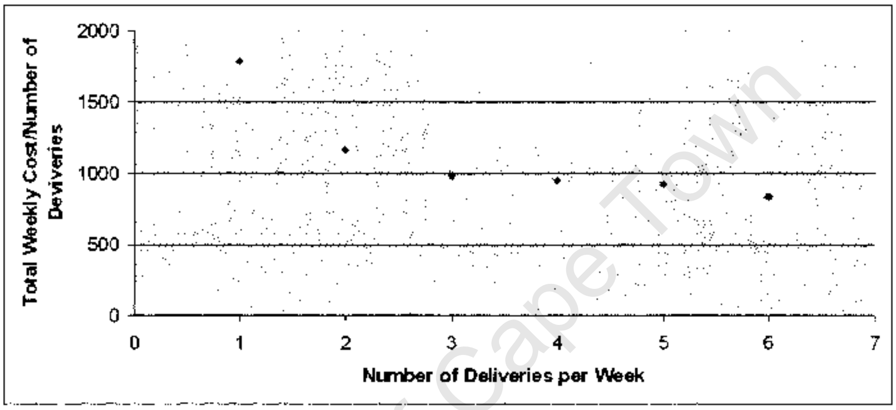


Figure 5.2: Weekly cost of delivery (Rand) for different numbers of deliveries per week for agencies

5.5.6 Pick-up radius

The pick-up radius (see the appendix of this chapter for how this was calculated) was varied in order to view the impact on the savings to the foodbank and the cost to the agencies. Table 5.4 shows the results. It can be seen that while a small pick-up radius results in roughly equal quantities of savings to the foodbank and costs to agencies, the overall logistics are hardly changed (a 5 kilometre pick-up radius alters total transportation costs by

. As this pick-up zone increases, naturally costs decrease for the foodbank, though the cost to agencies increases non-linearly with FBCT saving. If there are no deliveries and all agencies pick up from the foodbank, R1,700 will be saved per week for the foodbank though at a R10,900 cost to agencies per week.

Table 5.4: Weekly transportation costs (Rand) incurred by FBCT and agencies for delivery and resultant FBCT saving for different pick-up radii

Pick-up radius	FBCT cost	FBCT saving	agency cost
0	5275	0	0
5	5102	173	211
10	4825	450	1296
20	4206	1069	5661
infinite	3536	1739	10860

5.5.7 Converting Distance Travelled to Total Variable Cost

So far only petrol costs have been assessed. Other variable costs were listed in Section 5.4.1 and included driver salaries, vehicle maintenance and capital expenditure on vehicles. Vehicles are generally donated to the foodbank therefore capital expenditure is ignored. Vehicle maintenance was estimated at R2,000 per month per vehicle while the monthly driver salary was set at R4,500 per month. Nine vehicles with presumably nine monthly salaries would come to R58,500. The modelled monthly petrol cost at Philippi for this case was found to be R23,700, giving a total of R82,200 per month. Therefore petrol here would make up roughly 29% of the total variable costs incurred.

Appendix: Warehouse Location

List of Symbols

Symbols are split into "starting assumptions and constants" and those derived from the "starting assumptions and constants".

Starting assumptions and constants

- Decision variables:
  - — (xo) x coordinate of the warehouse
  - — (yo) y coordinate of the warehouse
- Constants:
  - — (a) Number of deliveries per week
  - — (0) Weight of distribution per week
  - — (d) Truck capacity
  - — *(p)* Petrol price
  - — *(1)* Fuel consumption (km per 1)
  - — (c) Travel time per km
  - — *(g)* Time at agency (to deliver food)
  - — *(h)* Working time per day
  - — *(1)* Time to load truck (when it leaves the warehouse)
  - — (7) Proportion of region covered
  - — (0) Air to road factor
- Region information (i = 1 to n denotes the region):
  - — *(xi; yi)* Midpoint for region i
  - — *(ri)* Radius for region i
  - — (zi) The number of agencies in region i

Derived symbols

- *(wi)* The road distance from the warehouse to the midpoint of each region *i*
- (vi) The average distance between agencies in a specific region *i*
- (p) The average number of agencies visited per trip
- (A) The average weight at each agency
- (147) The average distance from the warehouse to the first and last agency
- (V) The average distance in-between agencies
- *(Ui)* The number of *region trips* to region *i*
- *(4)* The number of left over agencies in region *i*
- (T) The average region trip length to each region *i*
- *(T)* The total distance covered to visit either all suppliers or agencies

Calculation of Pick-up Zone

Agencies within a given pick-up radius of the warehouse would need to collect food rather than have it delivered to them. In order to calculate the total transportation cost for the foodbank and for agencies for a given radius, a number of calculations are required:

- The number of agencies in each region that will collect;
- The distance each agency needs to travel:
- The new distance for the foodbank to travel to a region (this will change as the centre of the part of the region that does not pick-up is further away than the "old" centre); and
- For regions where the centre point has changed (see previous bullet), the new coordinates of the centre point will be required for use in the Clarke-Wright algorithm.

Each of these calculations will now be explained.

Calculating the number of agencies in each region that will collect
For each region, a proportion of the agencies would need to collect food from the foodbank rather than having it delivered, depending on the distance of the agency from the foodbank. Figure 5.3 shows the pick-up "zone" for agencies as a circle with radius x centred at the warehouse. Intersecting this pick-up zone is a hypothetical region.

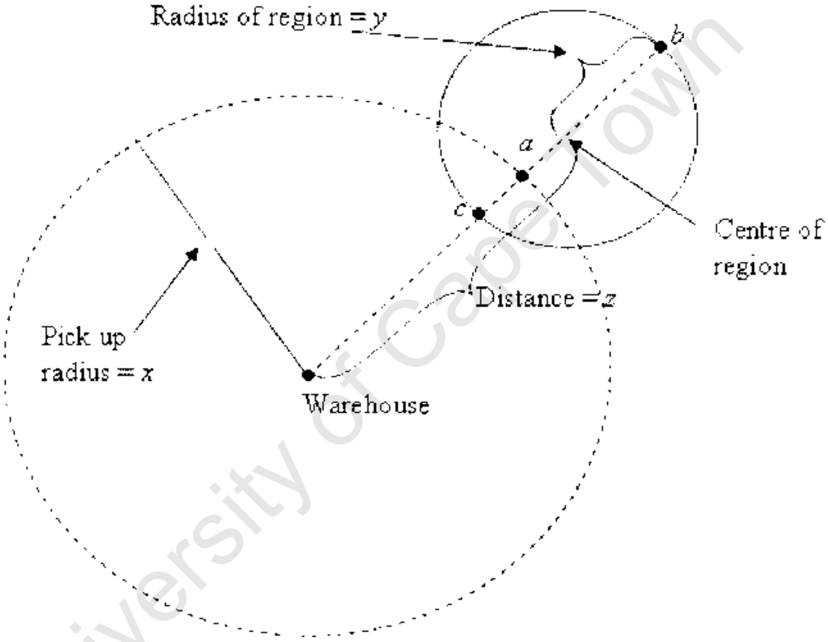


Figure 5.3: Illustration of pick-up zone

The proportion of the region covered by the pick-up zone is used as a proxy for the proportion of agencies (P) in the region that would need to collect food from the warehouse. An exact formula for the area of the intersection is given as [Weisstein, a]:

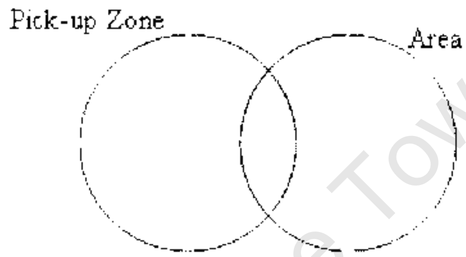
$$A = y^2 \cos^{-1}\left(\frac{z^2 + y^2 - x^2}{2zy}\right) + x^2 \cos^{-1}\left(\frac{z^2 + x^2 - y^2}{2zx}\right) - \frac{1}{2}\sqrt{E}. \qquad (5.4)$$

where $E = (-z + y + x)(z + y - x)(z - y + x)(z + y + x)$. The area of the region is given as πy^2, resulting in P given as:

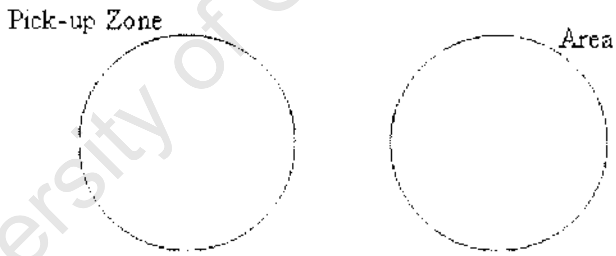
$$P = \frac{A}{\pi y^2} \qquad (5.5)$$

The above formula only works when the two circles "neatly" overlap. Extra stipulations needed to be inserted to make sure that the function behaved correctly. In total there are four possible scenarios:

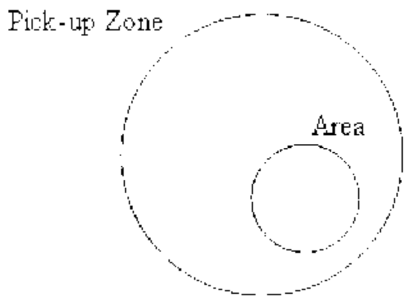
- *Scenario 1*: Neat overlap: P as in above formula



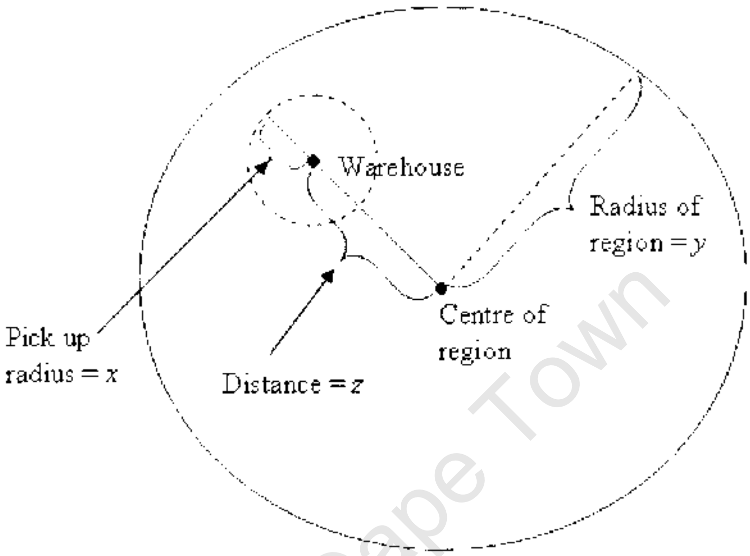
- *Scenario 2*: No intersection; $P = 0$



- *Scenario 3*: Region subset of pick-up zone; $P = 1$



- *Scenario 4*: Pick-up zone is a subset of the region: $P = \frac{\pi x^2}{\pi y^2} = \frac{x^2}{y^2}$



Calculating the pick-up distance for agencies and drop-off distance for the foodbank Incidentally, the pick-up zone impacts the distance needed to travel from the warehouse to a specific region, as the centre of the part of the region that does not pick-up is further away than the "true" centre. Depending on which scenario the area falls under (as previously defined), different formulae will be required to calculate the pick-up distance for agencies and the drop-off distance for the foodbank.

- *Scenario 1:* If the "pick-up zone" intersects with the region, then the closest agencies to the warehouse will pick up while the furthest agencies will need to be delivered to. An estimate of the new -centre" of the region to travel to can be given by the midpoint between points a and b on Figure 5.3. The new distance to travel to the first agency and to travel back to the warehouse after visiting the last agency would then be given by:

$$\frac{(distance\ to\ a) + (distance\ to\ b)}{2} = \frac{x + y + z}{2} \tag{5.6}$$

In the same way the distance for agencies to pick up food can be calculated as the midpoint between points a and c:

$$\frac{(distance\ to\ a) + (distance\ to\ c)}{2} = \frac{x + z - y}{2} \tag{5.7}$$

- *Scenario 2:* If there is no intersection the usual Euclidean distance is reverted to for both pick-up and drop-off.
- *Scenario 3:* For pick-up the usual Euclidean distance is used; drop-off is not required as the proportion of pick-up will be I.
- *Scenario* 4: The best estimate for the distance for pick-up is 0.92x, which is the average value for the distance from any point in a circle to the centre [de Jong, 2008]. For drop-off, the Euclidean distance between the centre of the region and the warehouse seemed too high as in routing the first and last agency would tend to be close to the warehouse. As a result the maximum of the distance between agencies (vi) and x was used. This would probably be slightly less than the "true" value, but the increase in precision gained for a better measure is negligible considering this is a special case when the pick-up radius is small, and even when it is so, it only impacts the region within which it is contained.

A summary of the proportions and distances for pick-up and drop-off are given in Table 5.5.

Calculating coordinates for the Clarke-Wright algorithm The coordinates for the centre of regions where agencies travel from when picking up is not required as these trips are simply to the warehouse and back and the distance is therefore sufficient. Similarly, drop-off coordinates for scenarios 2, 3 and 4 are not required as the drop-off centre points would be the same as before. Therefore all that is required is the coordinates of the new drop-off centre and pick-up centre for scenario I, which is now explained with reference to Figure 5.3.

Pick-up and drop-off centres are denoted as $(x_p; y_p)$ and $(x_d; y_d)$ respectively. x, y and z are known. Similarly the coordinates of the warehouse $(x_w; y_w)$ and the region $(x_r; y_r)$ are known. $(x_p; y_p)$ will be the midpoint between points a and c and $(x_d; y_d)$ will be the midpoint between a and b. Let the coordinates of a, b and c be denoted $(x_a; y_a)$, $(x_b; y_b)$ and $(x_c; y_c)$ respectively. Then $x_p = \frac{x_a+x_c}{2}$, $y_p = \frac{y_a+y_c}{2}$, $x_d = \frac{x_a+x_b}{2}$ and $y_d = \frac{y_a+y_b}{2}$. Therefore all that is still required is to calculate x_a, y_a, x_b, y_b and x_c, y_c.

To calculate x_b, one can imagine starting at x_w and then adding on the difference between x_r and x_w, multiplied by the ratio $\frac{y-z}{x}$. This gives $x_b = x_w + \frac{y+z}{x}(x_r - x_w)$. Similarly, $y_b = y_w + \frac{y+z}{x}(y_r - y_w)$.

Table 5.5: Summary of the proportions and distances for pick-up and drop-off

Scenario	Occurrence	Proportion	Pick-up distance	Drop-off distance
1	$z - y < x < z + y$	Equation 5.5	$\frac{x+z-y}{2}$	$\frac{x+z+y}{2}$
2	$z - y > x$	0	z	z
3	$z + y < x$	1	z	n/a
4	$y > z + x$	$\frac{x^2}{y^2}$	$max(v_i; x)$	

Applying the same methodology, the coordinates for c can be obtained. This time, however, the ratio will be $\frac{y-z}{x}$. Therefore $x_c = x_w + \frac{y-z}{x}(x_r - x_w)$ and $y_c = y_w + \frac{y-z}{x}(y_r - y_w)$.

Finally, for a, the ratio will be $\frac{x}{z}$, resulting in $x_a = x_w + \frac{x}{z}(x_r - x_w)$ and $y_a = y_w + \frac{x}{z}(y_r - y_w)$.

For each region i, the associated proportion of agencies that pick up can now be calculated along with the average distance travelled by agencies for pick-up per region.

Figures

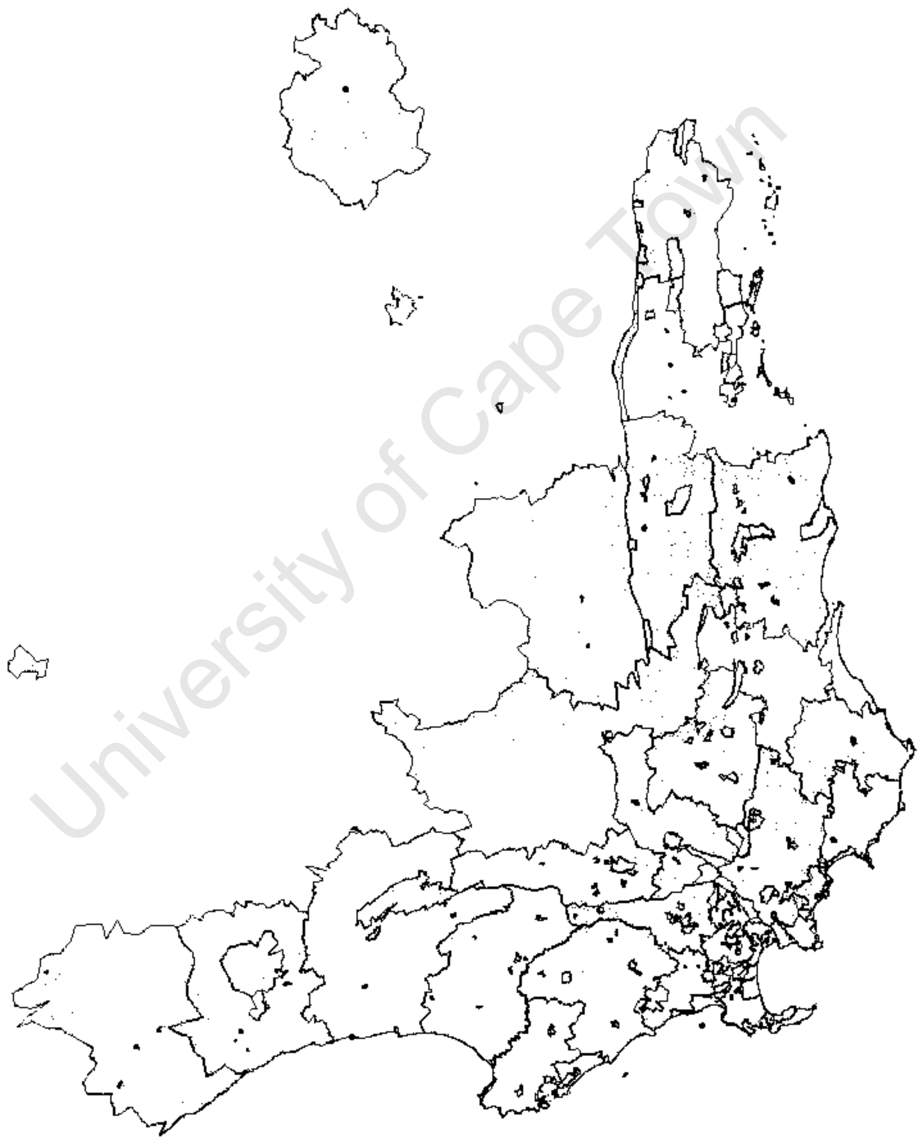


Figure 5.4: Main places of Western Cape

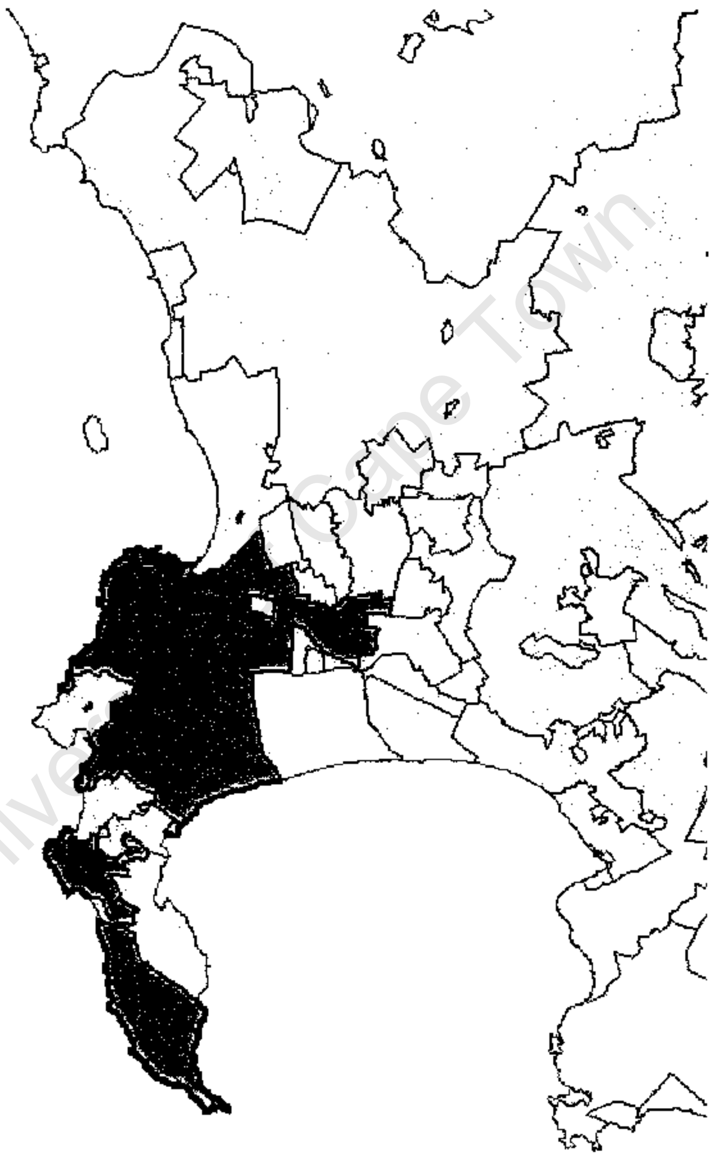


Figure 5.5: "Cape Town" main place

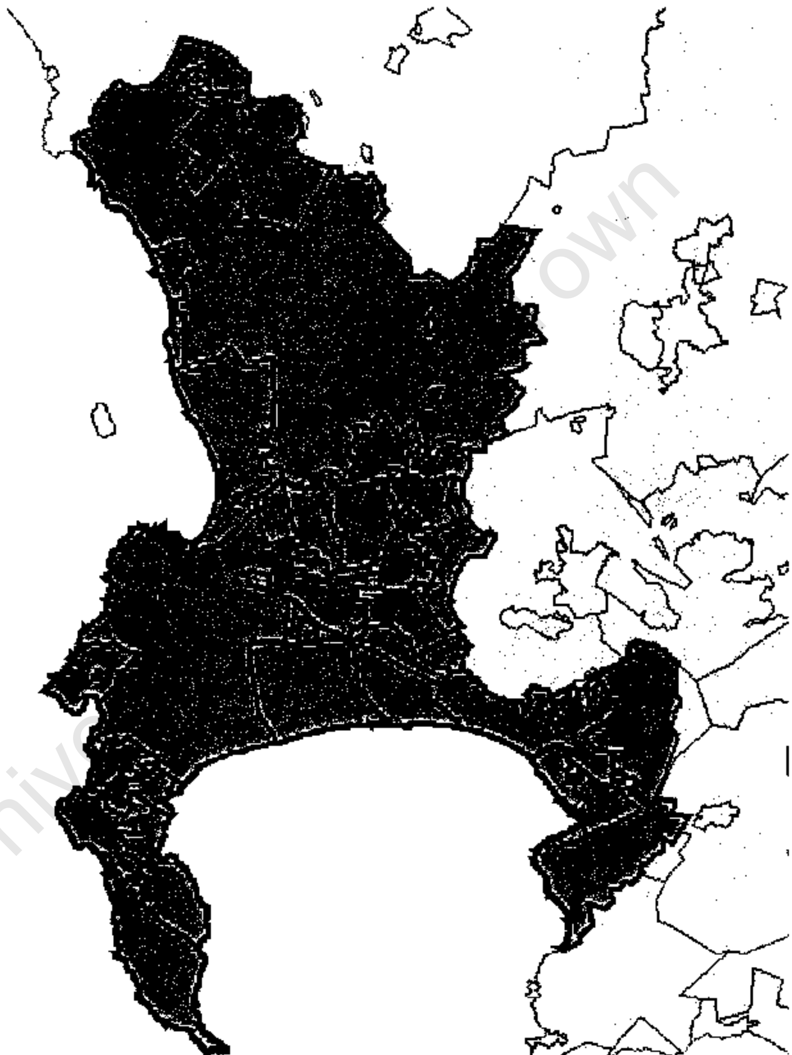


Figure 5.6: Approximate area of operation for FBCT

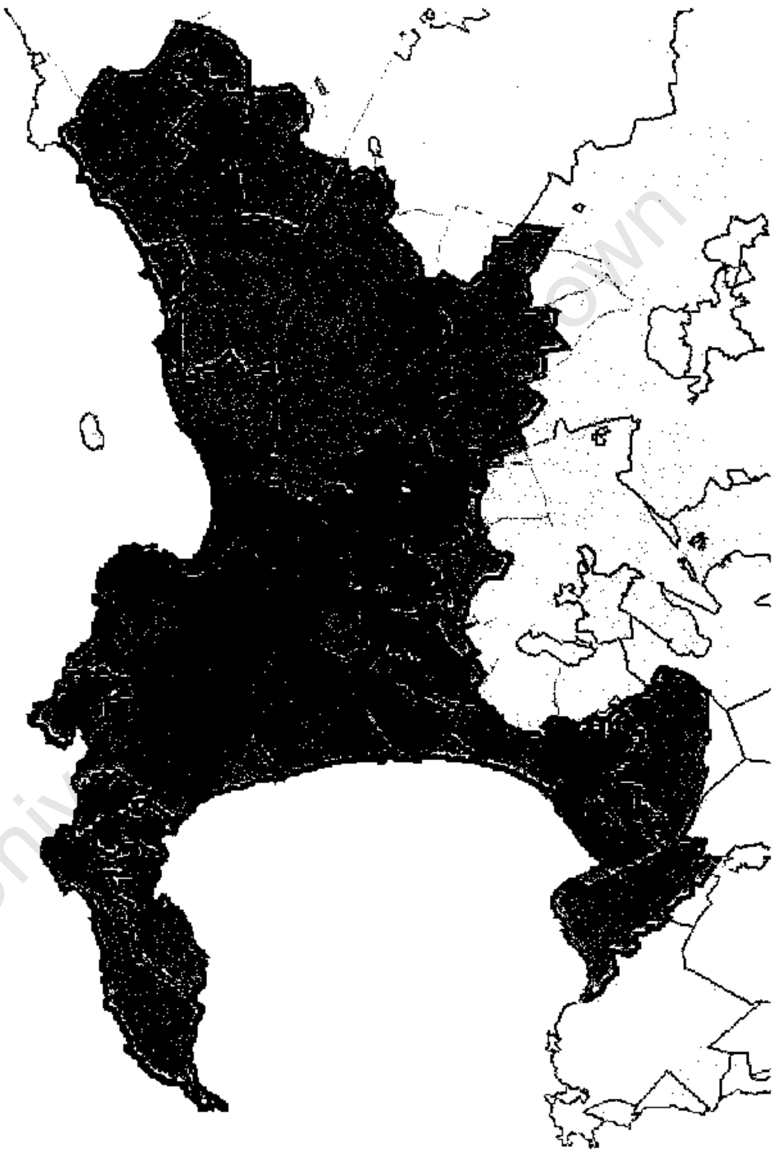


Figure 5.7: Area of operation for FBCT with a road network overlaid

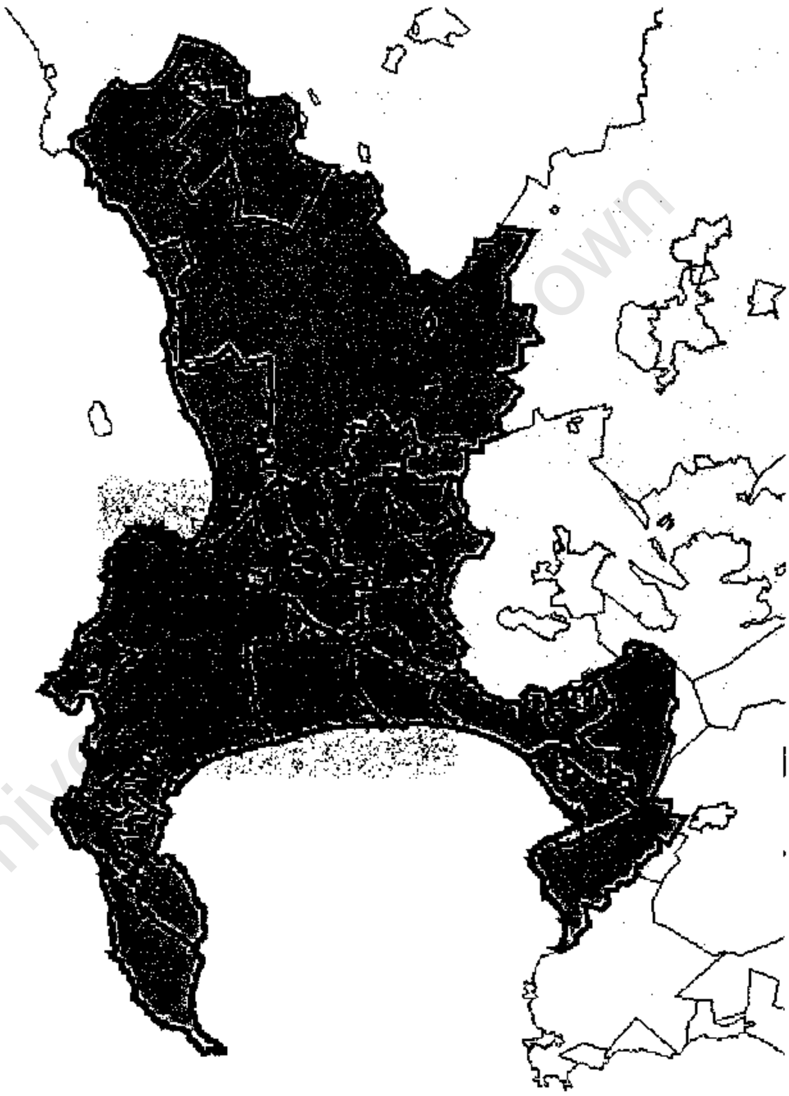


Figure 5.8: Area of cost locations (in red) overlaid on the area of operation for FBCT (in yellow)

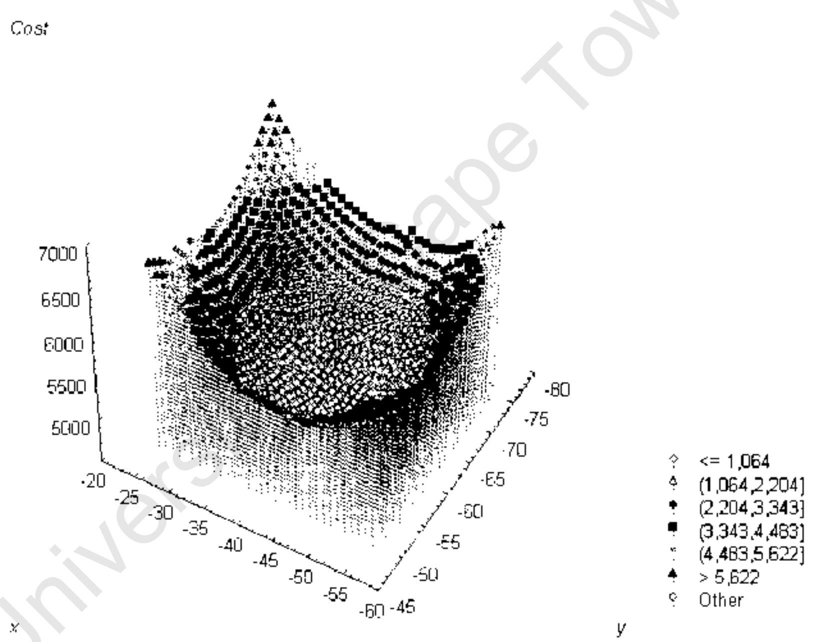


Figure 5.9: 3-dimensional scatter plot of weekly transportation cost as per the coordinates of the warehouse for current suppliers and beneficiaries)

Figure 5.10: The main places of Mitchell's Plain, Guguletu, Khayelitsha, Nyanga, Crossroads and Langa)

Tables

Table 5.6: Annual income categories (Rand) defined by StatsSA

Category number	Income interval
1	No income
2	R1 - R4,800
3	R4,801 - R 9,600
4	R9,601 - R19,200
5	R19,201 - R 38,400
6	R38,401 - R 76,800
7	R76,801 - R153,600
8	R153,601 - R307,200
9	R307,201 - R614,400
10	R614,401 - R1,228,800
11	R1,228,801 - R2,457,600
12	R2,457,601 and more
13	Not applicable (institutions)
14	Total

Table 5.7: Weekly transportation costs for delivery (Rand) for different numbers of deliveries per week

Deliveries per Week	Cost	Number of Drop-offs
1	1784	10
2	2338	20
3	2965	30
4	3805	41
5	4628	51
6	5019	61

Chapter 6

Decision Support for the Allocation of Food Resources

Unfortunately, in South Africa, the demand for food from the foodbank far out-weighs the supply. The aim of this research was therefore to create a model to assist FoodBank Cape Town with allocating food resources to potential recipient agencies such that humanitarian benefit is maximized. Due to the ill-defined nature of the problem, it was decided that the best approach would be to facilitate a series of workshops for FBCT representatives in order to construct the model. This would help better structure the problem and importantly also create ownership for the participants.

Section 6.1 details the composition of the participants. The model building is then split into two parts: Section 6.2, which describes the overall model; and Section 6.3, which describes in detail a critical component of the model, scoring an agency using MCDM. Sections 6.4 and 6.5 then describe how the model is optimized and how the model will be implemented.

6.1 Description of Workshop Participants

An important part of the process was selecting participants, particularly considering that one of the facets of foodbanking stressed by GFN was the need for community ownership and inclusiveness. There were already a number of people in the Cape Town Foodbank Forum meetings who held prominent roles in organizations with feeding programmes. This group of people was ideal for participation in the workshops for a number of reasons:

1. They understood both what foodbanking was about as well as the need for an allocation model;

2. They had valuable "on-the-ground" experience of feeding and developing underprivileged people;

3. They had an understanding of the South African NGO context and the kinds of agencies the foodbank would most like to support; and

4. They came from a diverse range of organizations, which would result in different viewpoints and therefore insightful discussion.

In addition, through humanitarian networks with those in the forum, other people who held similar positions could be reached. Importantly, representatives from Feedback attended. This was critical for two reasons.

1. They had a number of years of experience of operating as a quasi-foodbank. In this capacity, they needed to make decisions about who should be given food as well as how much. In dealing with this problem, they had already developed some of their own criteria.

2. Their staff would eventually work for the foodbank. Throughout the process, they had two members who were actively involved: one was set to become the Cape Town Foodbank Director and the other would become the Agency Liaison and would be responsible for food allocation. The importance of such key decision-makers' participation is stressed in great length in the literature on soft OR techniques as it would ultimately create buy-in into the model and therefore a greater desire to use it.

6.2 Model Description

This section describes the overall model developed and in so doing indicates how the agency score is incorporated. The objective is to maximize the total humanitarian benefit derived from food distribution, where the decision variables are the weights of food to be given to each agency. When giving food to an agency, benefit is derived from:

- The agency handling it, through the effectiveness and efficiency of its operation (aggregate benefit denoted Ai for each agency); and

- The region being served, defined as a geographical area with an associated proportion of poverty, as FBCT has a goal to distribute food in accordance with the spread of overall poverty over the greater Cape Town area (aggregate benefit denoted Ri for each region).

Total humanitarian benefit is subsequently modelled as an additive function, summing the benefits derived from each agency and each region. Food is indirectly allocated to regions by allocating food to agencies that supply to those regions. The total benefit (denoted *T)* is given as:

$$T = \alpha \sum_i A_i + (1 - \alpha) \sum_j R_j, \tag{6.1}$$

where 0 < < 1 is a constant used to scale the total benefits from agencies and regions so that they are comparable with each other and have appropriate weighting (details of æ are given in Section 6.2.3). The modelling of Ai and *Ri* will now be explained, after which some of the details are examined.

6.2.1 Modelling Agency Benefit (Ai)

Each agency has a certain desired weight of food, denoted ***Mi.*** Let *xi* be the weight of food given to agency *i.* Then zi = *xi//t/i* is the proportion of need satisfied for agency *i.* A value function was used to determine the associated value of meeting a certain proportion of need. For simplicity, this function is assumed to be the same across all agencies and is denoted as V(z) (details of V(z) are given in Section 6.2.3).

For a specific agency ***i,*** the value calculated from V(z) will need to be scaled according to the size of the agency in order to determine the actual humanitarian benefit realized. Assume, for example, that agency 1 requires *t* times as much food as agency 2 (i.e. /1/i = *tA/2)* and that they are identical in all other regards. It was decided that there would be *t* times as much value in satisfying proportion *p* of agency 1's need as there would be in satisfying proportion *p* of agency 2's need. V(z) is therefore scaled by the size of the need of the agency, M.

In evaluating an agency's effectiveness and efficiency, there are a number of potentially conflicting criteria. An MCDM process was therefore used to score agencies from 0 to 100 (see Section 6.3). Let Si be the score for agency ***i.*** *U(S)* (see Section 6.2.3 for details) is then the function that denotes the value of giving food to an agency with score *S.*

Both MV(z) and *U(Si)* have a ratio interpretation as they range from 0 (no worth) to 100 (maximum worth), with intermediary values being in proportion to these values. The total benefit from giving food to agency ***i*** can therefore be modelled as a multiple of these two components: Ai = ./1/si V(i)Ur(S'i).

6.2.2 Modelling Region Benefit (R_j)

Let a_{ij} be the proportion of food to agency i which goes to region j. Then $y_j = \sum_i a_{ij} x_i$ is the amount of food allocated to region j. Let K again be the amount of food the foodbank has to distribute and p_j the proportion of overall poverty in region j (obtained through poverty statistics). The desired amount of food to be given to region j is then given as $N_j = Kp_j$. The proportion of this desired amount met can be calculated as y_j/N_j and again a value function placed on this. Let $\phi(y_j/N_j)$ be the value (see Section 6.2.3 for details). Again, this is scaled by the proportion of need for area j. The total benefit from giving food to region j is therefore given as $N_j\phi(y_j/N_j)$.

As only the relative proportion for each region is important, different poverty measures can easily be alternated. At current a poverty measure was developed in Chapter 5, which measured the number of poor people per "main place" level. However this measure may prove to be too coarse, in which case the same measure can be used by "sub place" level. Another possible, more accurate poverty measure, is a poverty gap. This adds up all the differences between poor peoples' income and the poverty line for an area, therefore giving the amount of money required for an area to lift all their people out of poverty.

6.2.3 Modelling Details

The details of the constants and functions given in the model are now presented, though research into this area is still continuing. Currently, a sample of agencies (chosen to represent a broad spectrum of the kinds of agencies the foodbank encounters) are completing a trial questionnaire (available on the attached CD) in order to illicit agency scores, region information and food needs. Using the information from this questionnaire, different calibrations of functions and constants will be tested and shown to participants until they are satisfied that the model functions appropriately.

Scaling Constant,

The constant a is yet to be determined. As it is difficult to place an intuitive meaning on this, it will be dealt with once all other model specifications have been determined.

Desired weight of food for agency *i,*

Currently, the foodbank aims to supply a proportion of an agency's feeding activity. The desired weight of food is therefore the total weight of food an agency provides to its beneficiaries, however the foodbank only aims to support up to one meal per day. On a weekly interval M is therefore given as pdw, where p is the number of people served per meal, d is the number of days of the week that meals are provided, and w is the weight per meal. It is envisioned that this function could later be adjusted to incorporate other sources of food an agency acquires so as to better determine what an agency "needs" from the foodbank. Another possible extension is to assess how many more meals agencies could be providing if they had the available food resources.

Value of giving proportion *z* of food to an agency, $V(z)$

Through the workshops, it was determined that this function would be sigmoidal (see Figure 6.1). Participants stated that if only a small proportion of an agency's need is met, there is relatively very little value in this. For this reason there is a certain minimum threshold level a which is the minimum amount of food that should be given to an agency if any food is given at all. On the other hand, once a large proportion of need is satisfied the marginal return on extra food received decreases. Participants placed a tentative value of 40% on a. Other details of the function are still to be completed.

Value of giving food to an agency with score S, $U(S)$

If utility (y-axis) and score (x-axis) both range from 0 to 100, then this function will be continuously increasing over (0; a) and (100; 100), where a is some constant giving the percentage value of giving food to an agency with score 0 in comparison to an agency with score 100. The remaining details of the function will be determined before other calibrations by asking participants to compare perceived values of differently scoring agencies, predominantly to determine whether the function is linear or how it may deviate from linearity.

Value of giving proportion yIN of food to a region, *(1)(yIN)*

It was determined through the workshops that. if utility (y-axis) and proportion of desired food given (x-axis) both range from 0 to 100, then this

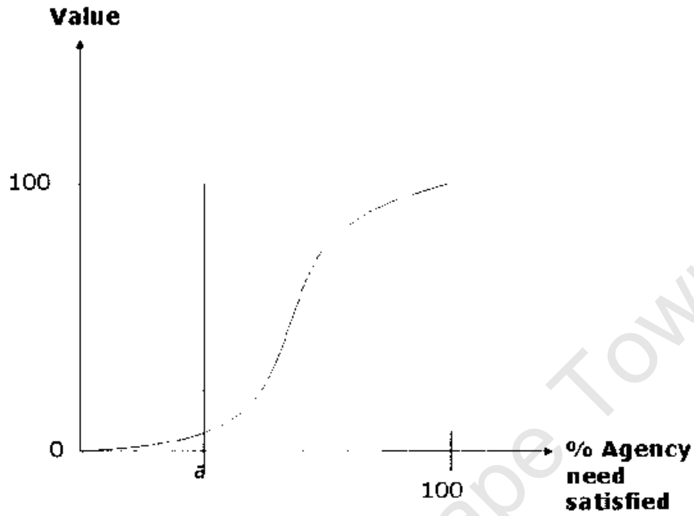


Figure 6.1: Plot of the utility in satisfying different levels of proportion of agency need satisfied

function is concave from (0; 0) to (100; 100). The remaining details of the function (i.e. degree of concavity) will also be determined before other calibrations by asking participants to compare perceived values of different proportions of need satisfied.

6.3 Developing a Scoring System for Agencies

The specific MCDM methodology used for scoring was Multi-Attribute Value Theory (MAVT), which develops scores as a weighted sum of values for criteria (i.e. the score for an agency *i* can be denoted by Si = Ek *217k7ik(i),* where *wk* is the weight of criterion *k* depicting its relative importance, and *fuk(i)* is the value score of agency *i* for criterion ***k).*** The criteria, their value scores and their associated weights were developed by facilitating a series of five 3-hour workshops. In between these workshops there was back-room analysis as well as occasional extra questions/work for the participants.

The process that participants were taken through is first explained (Sections 6.3.1 and 6.3.2), after which the resultant criteria are presented in Section 6.3.3. Although the process is presented in a straightforward step-by-step manner, in reality previous steps were often revisited.

6.3.1 Developing Criteria and Scenarios

The first three workshops were used to develop criteria and define the particular scenarios that could be realized under criteria.

Introductions and opening statements

The process began with a brief introduction of the process and a chance for participants to say whom they were and what they hoped to achieve. This helped in introducing participants as well as gaining an understanding of their views and backgrounds. Some of the main objectives for individuals were:

1. For food allocation to be open and transparent and to be based on explicit criteria rather than favouritism;
2. A desire to see and learn how food will be allocated in a very large and complex setting;
3. To possibly use the resultant model for food allocation at other community foodbank forums; and
4. To compare the individuals' organization's criteria with the end criteria of the process as well as other organizations' criteria so that improvements to their own organizations could be made.

Brainstorming session and clustering

The acronym "CAUSE- (criteria, alternatives, uncertainty, stakeholders and environment) [Belton and Stewart, 2002] was displayed and explained. This acronym provides a framework for structuring problems in an MCDM context. A question was also displayed as a starting point for generating ideas. This question was:

"What are the important factors to be considered when deciding:

1. To which agencies to give food;
2. How much food to give; and
3. What type of food to give?"

Blank paper was placed on a wall and split up into the different categories of CAUSE. Individuals were then given post-its to write ideas down and stick them on the wall according to where they fitted in under the CAUSE categories. Participants were encouraged to place similar ideas next to each other. Once this was done, the group, with the aid of the facilitator, continued to group similar ideas together until general clusters were established. Attention was then focused on the category "Criteria", under which general clusters were further grouped where applicable. These general clusters were termed "main criteria" and had "sub criteria" under them.

Operational definitions of criteria

Once the main criteria were established, participants were split into groups and asked to write a short description of what the best imaginable scenario for a particular criterion would look like; what the worst imaginable scenario would look like; as well as two or three intermediate scenarios. This discussion helped to provide a clear definition as to what was meant by specific criteria and formed the basis for different scenarios under criteria.

Defining main and sub criteria in more detail

After the initial round of defining main and sub criteria, participants were able to openly debate the validity of certain criteria and refine what was originally put forward. Part of the back-room analysis involved identifying and suggesting criteria that Feedback (one of the merging organizations) had previously developed and used but were not mentioned in the workshop. The following concept was repeatedly presented to participants in order to determine whether criteria were important or not: "Imagine you have only one meal available and you need to decide which one of two hungry people to give it to. These two people are identical in terms of all criteria except the one in question. Would knowledge of the new criterion help you to decide whom to give the meal to? If so, the criterion is important. If not, then it is not   It was also important to remind participants that although poverty was not measured in the agency score it would be measured at an area level. Therefore, when comparing two people, it would need to be assumed that they come from the same area. However, even though area is used as a proxy for poverty, two people in the same area could differ in poverty depending on the presence of another criterion. In this case, the presence of the additional criterion would be important and would need to be included in scoring the agency.

Early in the process, challenges arose due to a lack of continuity with the participants (of the six attendees at the second workshop, only two were at the first workshop). This was generally due to participants sending in colleagues in their place. This resulted in debate and confusion around the outcomes of the first workshop and progress was hampered. In order to prevent a re-occurrence of these problems, the group decided that there would be no new participants for subsequent workshops. A core of reliable members was then achieved and the process progressed smoothly for the remainder of its duration.

6.3.2 Scoring Scenarios and Weighting Criteria

Each end-level criterion (defined as a criterion with no sub criteria) required a scoring system for its scenarios and a weight that would specify its relative importance to other end-level criteria. The concepts of scoring and weighting were introduced to participants and a couple of criteria were scored as a group exercise. In this process the criteria were further refined where necessary. Two workshops were conducted for this part of the process. In order to minimize workshop time a questionnaire (given on the attached CD) was constructed for participants to complete in between workshops. This questionnaire was aimed at eliciting the remaining scores and weights as well as checking for any potential preferential dependencies between criteria. The latter workshop was used to go over these results and make necessary changes. This also allowed for debate between participants due to any differences in opinion.

Scoring

Criteria were scored from 0 to 100. The best-case scenario under a certain criterion would receive a score of 100 while the worst-case scenario would receive a score of 0 (best-case being the most deserving of food support). Participants were asked to picture the increase in value in going from the worst-case to the best-case scenario (a range of 100) and to compare this with the increase in value in going from the worst-case scenario to the intermediate ones (i.e. if the increase in value to an intermediate scenario was seen as half of that from the worst-case to the best-case, that particular scenario would receive a score of 50). Through discussion and using examples, the basic idea was soon understood by the participants and the scoring then became straightforward. Bar charts were used at times as visual comparisons as these were sometimes easier to conceptualize than numeric comparisons for participants.

Weighting

A bottom-up approach was used whereby end-level criteria under the same higher-level criterion were first weighted, after which comparisons across "families" of end-level criteria were made in order to determine the cumulative weight for each criterion. In each instance, a set of criteria (usually three at a time) were used to construct different "situations" for participants (a situation is defined by specifying a scenario for each of the criteria used). The principle of swing weighting was also used, which resulted in the following: each situation had one of the criteria set at its best-case while the others were set at their worst-case (unless this was felt to be too extreme to be easily envisaged, in which case intermediate cases would be used). The participants were then asked to pick which situation should get the highest priority for food support, followed by the second highest priority, etc. This would give a rank ordering of the criteria. The participants were asked to envisage their top priority to have a score of 100 and to score the other situations relative to this. After the weights were computed, the results were reflected back to the participants for a validity check.

Preferential independence

As an additive model is used, preferential independence must be satisfied. As a comprehensive check is lengthy, direct tests of additivity were instead performed and no substantial violations were found. These tests involved taking two criteria and asking participants for their perceived value of the highest scoring scenarios on each individually, versus their perceived value of a combination of the highest scoring scenarios for both criteria. Suppose that in any particular case, the presence of one criterion seemed to diminish the value of the second, resulting in the sum of the values from the individual criteria not equating to their combined value. In such a case, we would have to conclude that the additivity assumption is violated.

6.3.3 Results

Figure 6.2 shows a value tree of the final criteria. There are two main criteria: "Demographics", which refers to certain attributes of the agency's beneficiaries; and "Operation and Management of the Organization", which attempts to measure the level of service the agency provides. The end-level criteria are explained ill more detail in the ensuing sub-sections, however.

additional stipulations are first presented. These stipulations act as hurdles, and any agency not meeting them will not be allocated food. Table 6.1 shows the resultant weights on end-level criteria and the respective scores for different scenarios under criteria.

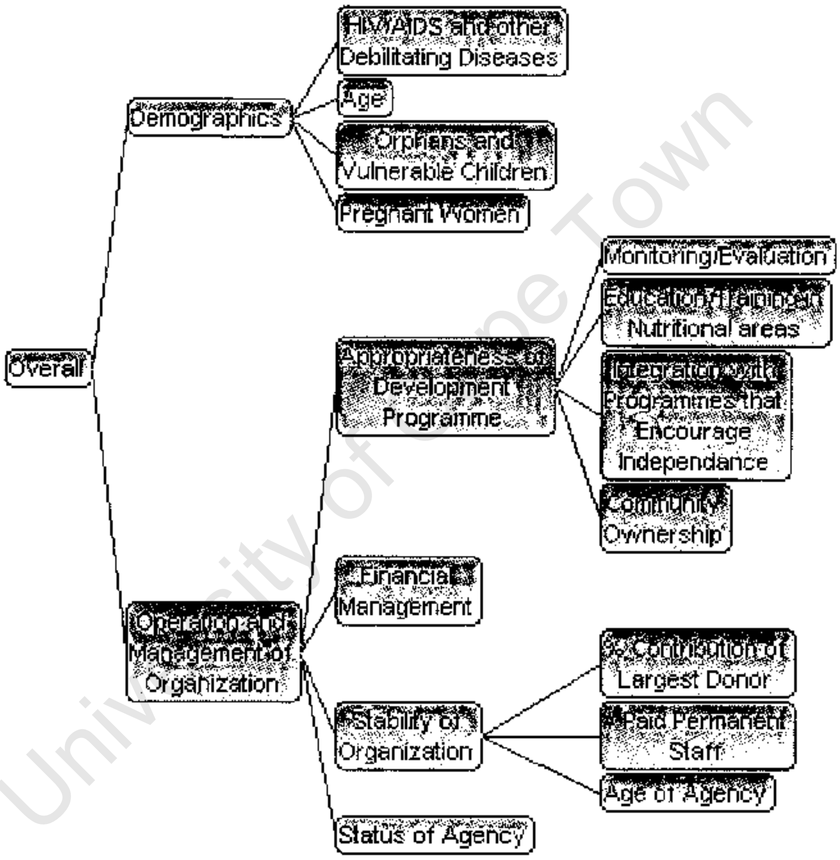


Figure 6.2: Criteria used to develop a score for agencies

Extra stipulations

These stipulations, which relate to issues including governance and record keeping, were expressed by the workshop participants as well as FBCT staff:

1. Feeding with the purpose of poverty alleviation must be a primary goal of the organization;

Table 6.1: Table showing all end-level criteria with their respective weights and scenarios with scores.

End-Level Criterion	Weight	Scenario	Score
HIV/AIDS and other Debilitating Diseases	100	Yes	100
		No	0
Age	100	Yes	100
		No	0
Orphans and Vulnerable Children	60	Yes	100
		No	0
Pregnant Women	60	Yes	100
		No	0
Monitoring/Evaluation	30	Yes	100
		No	0
Education/Training in Nutritional Areas	30	Yes	100
		No	0
Integration with Programmes that Encourage Independence	80	Yes	100
		No	0
Community Ownership	30	Average Above 50%	100
		Average Below 50%	0
Financial Management	80	3 Indicators Satisfied	100
		2 Indicators Satisfied	75
		1 Indicators Satisfied	25
		0 Indicators Satisfied	0
% Contribution of Largest Donor	35	Under 50	100
		50 to 75	75
		Over 75	0
# of Paid Permanent Staff	35	Over 8	100
		4 to 8	75
		Under 4	0
Age of Agency (Years)	35	Over 5	100
		2 to 5	75
		Under 2	0
Status of Agency	60	Valid NPO and PBO	100
		NPO only	75
		Not Registered	0

2. Food will only be given to agencies that respect differences of religion, race and nationality;

3. Agencies must meet FBCT's minimum food handling standards (though these standards are as yet unclear);

4. Agencies and their beneficiaries are not permitted to sell food;

5. Agencies will be required to keep a record of food received from the foodbank and attend a certain minimum number of agency meetings; and

6. All food given to an agency must be used for their beneficiaries and not passed on to other organizations.

Demographics

An explanation of each sub-criterion is given where necessary, as well as how this will be measured:

- *HIV/AIDS and other debilitating diseases.* This is a binary (yes/no) question. If the agency can adequately display that it has a strategy for targeting those with debilitating diseases, they receive a score of 100 on this criteria, otherwise 0.

- *Age.* Four age classes are defined: children of pre-schooling age, children of schooling age, adults, and the elderly. Each category/scenario receives a different score. Agencies are asked to give numbers per category from which a weighted average can is calculated as the score for *Age.*

- *Orphans and vulnerable children.* This is treated as a binary question in the same manner as *HIV/AIDS and other debilitating diseases.*

- *Pregnant women.* This is treated as a binary question in the same manner as *HIV/AIDS and other debilitating diseases.*

Operation and Management of agency

Each sub-criterion under "Operation and Management of agency" is now discussed.

Appropriateness of development programme Participants, and even members of the foodbank who were not involved with the workshops, stressed that food should not simply be handed out but that an agency's beneficiaries should be enrolled in a programme for development. Four indicators of a good developmental programme were developed. As with *HIV/AIDS and other debilitating diseases,* the score for each is binary. When scoring is done, a trained member of the foodbank will need to use their experience to decide whether the agency satisfies the criterion adequately or not. A brief description of each indicator is given below.

- *Monitoring/Evaluation.* An example of an appropriate strategy would be for an agency to take health measurements of their beneficiaries and to track their progress.
- *Education / training in nutritional areas.* Areas include hygiene, nutritional value of different food types, cooking/meal tips, farming education, etc.
- *Integration with programmes that develop independence.* The agency must have beneficiaries enrolled in a programme that will help to get them off food support. Note that this programme does not need to be provided by the actual agency that receives food. In some instances, there may be a partnership between the agency receiving food and another organization providing the programme. It was also stated that this would apply to children as steps could be taken to ensure that a child grows up with the necessary skills to become independent. The same applies to the elderly.
- *Community ownership.* This refers to whether the community takes ownership of the agency and is in a sense involved in it. This is measured by averaging the proportion of staff and board members that are from the local community. If this average is above 50% the agency, receives a score of 100, otherwise 0.

Financial management This was seen as being important in order for the organization to run well and for protection against the misuse of funding. There are three elements that were considered to be indicators of good financial management: the keeping of financial records, the use of a budget, and a separate bank account. In order for an agency to satisfy each. records must be submitted to the foodbank as proof. Each of these is binary and scoring for *financial management* goes according to whether one, two or three of these indicators are met. Participants felt that fulfilling two is very good (almost as good as fulfilling all three) while fulfilling one is very poor (almost the same value as fulfilling none). This is therefore reflected in the scoring.

Stability of organization This was aimed at establishing the longevity of the organization for the sake of the end-user, who would be reliant on this source of food. Three indicators were identified.

- *Percentage contribution of largest donor.* The larger the percentage of the largest donor, the more unstable the organization is seen to be.
- *Number of paid permanent staff.* It was noted that an organization with more paid permanent staff is generally more stable as it would tend to be better established.
- *Age of the agency.* Clearly, the older the agency the more likely it is of remaining in the future.

For each of these criteria, participants were asked for ranges of values that would correspond to good, average and poor performances, and were then asked to score these.

Status of organization This refers to whether an organization is registered as a Non-Profit Organization (NPO) and/or a Public Benefit Organization (PBO). The registration of the organization was seen as important as it provides some level of accountability and suggests a well-run organization. In order to satisfy this criterion, some form of proof of registration will need to be provided to the foodbank. It is not possible to register as a PBO if an agency is not registered as an NPO, therefore there are three possible scenarios: not registered, registered as an NPO, and registered as an NPO and PBO.

6.4 Model Optimization

An optimization procedure is required to calculate an optimal distribution of food. This represents future work, but it is conjectured that one of the approaches listed below might be implemented. As a starting point, it is assumed that a list of agencies is available with scores and food needs recorded for each. In addition, a certain average monthly inflow of food is assumed. One of the following procedures are then envisioned:

- To give linear approximations for the functions given by V(2,), $U(S)$ and $0(y\ IN)$, and to then use linear programming;
- To again use linear approximations, though to then use a goal programming approach, in which case o will no longer be required; or
- To programme a heuristic, though a greedy heuristic may be too simplistic as the marginal utility on VW is increasing for small proportions, meaning globally optimal solutions may not be realized due to locally inefficient "jumps".

Importantly the technique chosen must also be user-friendly for foodbank staff to implement.

6.5 Practical Implementation

Agencies will enter into a one-year contract with the foodbank, after which they will need to re-apply for the following year. It is assumed that all applications will happen simultaneously. In this case, an estimate will be made for anticipated food volumes to the foodbank for the up-coming year and the optimization run. The model would then allocate a certain food volume to each agency, which would be converted to a proportion of the foodbank's inflows. Throughout the year, agencies would receive a fixed proportion of the foodbank's inflows on a daily basis, rather than a varying proportion based on optimizing the model on a daily basis. The reason for this is that one of the key concerns of agencies is that food volumes should be as steady as possible. By allocating a proportion, "highs" and "lows" are shared among agencies. If the model were optimized daily, some agencies may receive nothing on a day of low inflow.

A possible later extension is to incorporate applications on a continuous basis throughout the year. This would need to be handled delicately due to the stochastic nature of inflows. The set of agencies should only be changed if there is a change in the mean of inflows. To determine whether changes in inflows are due to mean changes or statistical variation will be difficult and would probably require "ground" knowledge from foodbank staff of the factors that are causing changes. Once a decision is made to alter the composition of agencies, those agencies that bring the highest marginal utility would be added when inflows increase and those with lowest marginal utility would be taken off when inflows decrease. In addition. the contracts of agencies that are seen to perform poorly may not be renewed to make provision for agencies with higher utility. Finally, there is a human element, where the foodbank would not wish to act coldly toward agencies and simply trade "better" ones for "worse" ones. Some threshold level of difference may therefore be required or a policy of not stopping food support to an agency unless they diminish in their service.

At the time of writing, the research had been presented to the FBCT board of directors. It was well received and will be implemented when research is complete.

Chapter 7

Concluding Remarks

The conclusions, recommendations, practical implementation and further scope are all dealt with in the ensuing sections according to the research areas covered: "Aiding the CTFBF to establish FBCT" and "Warehouse Selection", which incorporates warehouse size and location. "Food Allocation- is not dealt with as this is still ongoing and concluding remarks were therefore covered in the respective chapter. Lastly, an "Overall" section gives general insights from the entire dissertation.

7.1 Aiding the CTFBF to establish FBCT

This section is divided according to issues relating to the causal mapping, workshop and project management.

7.1.1 Causal Mapping

A causal map was prepared in order to model the success of the foodbank and the important issues that impact on this. From the causal map, it seemed that the foodbank's success relies on its public image, as this is the foundation for a variety of re-enforcing loops. A successful image will therefore result in quick steady growth, while a poor reputation will he detrimental. This is particularly true for sourcing food as suppliers are typically very concerned about their brand being at risk: for example, if an individual becomes sick through eating food from the foodbank and this is traced back to them. In these cases, their supply of food is likely to suddenly stop and the foodbank will suffer decreased volumes of food as well as a damaged image for other potential donors.

In essence, the foodbank should exhibit classical S-shaped growth. The system is typically very responsive and there are no obvious time delays, therefore there should be very little or no oscillations. The carrying capacity also logically cannot be surpassed as the foodbank can only collect as much "waste" product as there is available, unless food is sourced through other means. In its early stages the only hindrance to growth is competition for "waste" food and a poor economy (though in South Africa the former should not play a major part as the "market" appears relatively untouched). Even considering the latter there is still a large potential for steady growth as there is a considerable amount of "waste" product being dumped, thus exponential growth can be expected in FBCT's early stages. In the long-term, the main restriction to the foodbank will be the "carrying capacity" of the system as there will not be a limitless supply of "waste" food. The amount of "waste- in the system will typically be determined by the spending power of customers (this will determine the size of the food market) and the controls that food organizations have in place. Therefore, innovative ideas will be required once the carrying capacity is reached if the foodbank is to continue to grow.

7.1.2 Workshop

The goals of helping to give the Cape Town FoodBank Forum more structure, a better sense of leadership, an enhanced understanding and a plan for the work to be covered in establishing a foodbank were all achieved (see Chapter 3 for details). One of the key stakeholders commented that the "answers" were obvious, but the actual process of assisting the participants to come up with the solutions created a far greater sense of ownership. Therefore, the actual functioning of the forum in working toward a foodbank after the workshop was far more successful.

7.1.3 Project Management

Over the course of the project the original plan was revisited a number of times by the co-chairs and forum to assess progress and the work to still be completed. At the time of writing, FBCT had already launched on 2 March 2009 without building or renovating. The project plan developed in this case had a completion date scheduled only three and a half weeks prior to this: and this completion date had been set 8 months in advance. This is also a credit to the co-chairs and their working teams, who were able to complete the work in a timely manner.

In many ways the project of setting up FBCT was a "complex" project [Williams, 2002] (pg. 58) due to the many "soft" issues involved. Although there is structural complexity as a result of the number of tasks and their interdependencies, most of the complexity is brought about by the "epistemic uncertainty" [Williams, 2002](pg. 56) in the methods for tasks and thus their timing (there is no clear sense of where funding will come from or how this will be done, how marketing or IT will be handled, whether a warehouse will be built from scratch or leased, etc.). There is even uncertainty in goals to an extent as although there is a clearer sense of leadership as a result of the workshop, there are still many other influences in this area, particularly from GFN and FBSA, who have a significant impact on FBCT and its direction.

A possible extension to better estimate risk and uncertainty for the project completion date could have been to place statistical distributions on task lengths. External factors and the impact these could potentially have on the project could also have been modelled. The "project length" could then be simulated a large number of times and the distribution observed on completion time.

7.2 Warehouse Selection

Conclusions and recommendations are first given for warehouse size and location. The actual warehouse selection that took place (practical implementation) is then given. Finally, further scope is addressed.

7.2.1 Conclusions and Recommendations for Warehouse Size

There were a variety of conclusions and recommendations to be drawn as a result of the many secondary objectives encountered to the warehouse size problem. Discussed are those relating to: Actual warehouse size requirements; internal requirements (i.e. the amount of cold storage required, the amount of waste to be handled, etc.) and inventory management. After this, further scope relating to the warehouse size is covered.

Warehouse size requirements

The 1200m2 case for Philippi was recommended as ideal with regard to warehouse size. Although the whole area would not be required when operations begin (only 440m2 would be needed), provided short-term growth is strong, 950m2 was estimated to be needed within a year while 1370m2 was seen as ideal for the long-term. Importantly, there is room for expansion if need be, which almost foregoes the risk of 1200m2 being too small in the long-term. Also, the warehouse would be leased, which further reduces the risk of a large capital investment through building. If other initiatives are started (e.g. inventory management to stabilize outflows, safety stocks, etc.), it was noted that warehouse requirements could approach the 20001112 mark. In this case the warehouse could be expanded or some of the contingency plans identified (see Section 4.5.4) could be employed.

When taking into account the uncertainty inherent in the model, it is also concluded that there is only a small amount of risk attached to obtaining a warehouse size largely different to the optimal. The major uncertainties in the analysis were related to the average weight placed on Lions' stores and the expected growth in the short and long-term. The former was found to influence required warehouse size by at most 14%. The warehouse size required also seemed fairly insensitive to changes in growth (which is shown when comparing short and long-term requirements) as the largest change expected is in an increased frequency in non-perishables, which has little impact on required warehouse size.

The original recommendation from GFN was that 1200m2 would be too small and that 2500m2 would be a minimum, while warehouses of up to 5000m2 would be adequate (Section 2.2). However, this was probably due to their experience in the US and the different context in which these food-banks operate. It is reasonable to assume that the US would generate far more surplus food per hungry individual than in South Africa, resulting in much larger "stocks" being generated. It appears that for the South African context, provided good inventory management and capacity for outbound logistics is maintained, stock levels should never reach large quantities. In addition. Cape Town in particular deals with mostly perishable produce, which is inherently very fast moving. Thus, it is important that sufficient logistical capacity is available for FBCT rather than excessively large warehouses, such that the product can move quickly through the system.

Internal requirements

The values obtained for the amount of waste, packaging, labelling and cold storage to be handled were presented to the client in order to give an idea of what to plan for. Due to the uncertainty of these values, the best approach envisaged was to take on stores in an incremental manner. It was recommended that each month a certain number of stores would be taken on from Lions. From this, better estimates could be obtained for the assumptions made. Capacity for waste, packaging and labelling could then be expanded as needed. As cold storage infrastructure is more costly and more difficult to expand upon continuously, a refrigerated container was recommended to be leased initially in order to get a better sense for these estimates. Simultaneously, the requirements for frozen storage could then be investigated in order to estimate how much would be required and how much this would reduce the required cold storage.

Inventory management

As only one decision rule was used for inventory management, this could largely be regarded as experimental. However, the rule performed well and certainly substantiates further research. However, one of the critical assumptions of this operating policy is that when perishable product is substituted for non-perishable product, the two must be exchangeable (e.g. tinned vegetables replacing fresh vegetables). In the current case, the non-perishables are extremely homogeneous (90% Weetbix and Iced Tea) and would not form a good substitute for perishables. Thus, the application of any research on inventory management would be pending a better mix of non-perishable product. The way the foodbank operates its inventory could also be particularly problematic during its early stages as there would likely be increasing inflows for a period of time. Therefore, it would be difficult to tell the difference between a peak due to statistical variation and an increase in mean. Management would therefore not know whether to increase the outflow factor (Section 4.4.2) or to hold stock for a "down period". On-the-ground experience and intuition will probably be required. A Bayesian approach could even be used whereby value judgements are initially used for "prior" distributions, and these gradually modified as time goes on and real data can be collected.

7.2.2 Conclusions and Recommendations for Warehouse Location

The Philippi warehouse was recommended as it was within the ideal "zone" (see Section 5.5.2) and near one of the major intersections. A number of other aspects were also covered as a result of the analysis of warehouse location. However, due to time constraints, the work in these areas was predominantly exploratory, therefore only a few tentative conclusions and recommendations are drawn.

- As a general rule, the optimal truck size would be one where the truck is big enough to do enough pick-ups and/or deliveries such that it only returns at the end of the day. An initial estimate of the trucks required is about nine or ten 2.5-tonners, though consideration would need to be given to the current fleet as well as routing in order to assess the additional vehicles required.
- It was shown that from a cost perspective of the total system (cost to the foodbank and to agencies), delivery to agencies would usually be preferred over the use of a pick-up radius.
- It was shown that increasing the number of deliveries per week does not increase the cost of delivery in proportion. Consultation with agencies would be required in order to place some "value" on an increased number of deliveries per week in order to determine whether this would be worth the increased financial cost. A delivery fee (which equals the cost of delivery) could also be used for agencies. In this case the agencies could then decide for themselves whether the financial cost is worth the increased delivery frequency.

7.2.3 Practical Implementation: Warehouse Selection

The warehouse at Philippi was recommended with regard to size and location. It was also found to perform well on all other criteria, therefore FBCT decided to lease the warehouse. The problem then arose as to whether to lease 600m2 or the full 1200m2 and one week was assigned by FBCT management to research the problem. The recommendation was then given to take the full 1200m2, however unfortunately the other 600m2 was taken during the research period. The agreement was to allow FBCT and their new -neighbour" to rent for 6 months. Both parties seemed to want the whole property at a later stage, therefore during this time the situation would be re-assessed and the decision given as to who would get the whole space. It was then decided to take the 600m2 rather than look for other premises due to a lack of other alternatives and a general sense that FBCT's chances of securing the full space after 6 months was good. As a result it was simply recommended to operate as though on a temporary basis (i.e. to not install frozen storage and to use a refrigerated container) to reduce the cost of a later move.

At the time of writing the "neighbour" had recently moved out and FBCT had secured the full space. The initial calculations also appear to be accurate as roughly 50% of the space is being utilized, though growth is ongoing and the full 1200m2 appears ideal for the medium to long-term. It is interesting to note that OR in this case was successfully implemented in a similar way to its inception in World War 2: by assessing how to best implement a new technology where there is no directly relevant previous experience. This also helped save a large amount of money as if the recommendation of a minimum of 2500m2 was followed and the space leased, at least R40,000 per month would have been wasted (using current market costs per square metre), which is substantial for an NGO starting up.

7.2.4 Further Scope

Further scope is split into areas relevant to warehouse size and areas relevant to warehouse location.

Warehouse Size

Firstly, areas in which the current research could be improved are discussed, after which new but related areas for research are presented.

Possible extensions to research undertaken:

- The shelf life of product can be taken into account; and
- Probability distributions could be placed on certain constants (e.g. ton/m3 for product inflows) as these in fact vary per donation.

Potential new research areas:

- Most notably, as time goes on estimates for assumptions made can be updated to give more accurate output;
- As previously stated, more research into good inventory management practice would almost certainly be beneficial, whereby non-perishable product could be used to smooth fluctuations in perishable product;
- Inventory management could be extended to take into account the nutritional composition of inflows and outflows and to ensure balanced meals go out;
- A purchasing programme could be explored and the impact that this would have on inventory management;

- Frozen storage needs to be assessed along with how this inventory should be managed;
- In conjunction with inventory management, the value of a bigger warehouse (required for more flexible inventory management) could be compared to the opportunity cost of this extra space (extra food could perhaps be bought); and
- Although the daily amount of packaging, sorting, cleaning, etc. were addressed, it would he more helpful to observe work load against time as there may be sudden spikes for which more staff will be required.

Warehouse Location

With regard to improving the research undertaken, the main improvement could have been made by using a road network and the actual addresses of suppliers and agencies. This would then also prove helpful for possible further research into vehicle routing and scheduling for collections and deliveries. Currently this is done ad hoc: a method that will become more difficult and inefficient as operations expand. This routing algorithm would reduce travelling time required and therefore costs.

7.3 Overall Observations

Through the foodbanking experience, Operational Research appears to be a field that has much to offer the humanitarian sector. Significant problems were able to be tackled in this dissertation, ranging from the more technical (warehouse size and location) to those of a more social nature (helping to establish leadership for the foodbank and manage the project, and developing a food allocation model). Both areas were of significant importance to the foodbank. The former in this case helped to reduce costs in an already tight budget, while the latter helped to better define and reach the goals of the foodbank.

Differences, predominantly around goals and uncertainty, were observed between the research undertaken and what would be typical of operational research in industry. These are discussed individually below, after which the experience of dealing with clients in a developmental context is explained.

7.3.1 Goals

When modelling, the biggest difference was found to be in goals (humanitarian benefit for a developmental context versus profit for an industry context). This sometimes created "fuzziness" for the developmental context (e.g. how to rate agencies for food allocation), which would result in problem structuring techniques requiring the focus, rather than intricate mathematical modelling.

7.3.2 Uncertainty

There is greater overall uncertainty in the developing world. Uncertainty can be split into "hard", which can generally have probability distributions fitted to it; and "soft", which is of a more "fuzzy" nature and is more difficult to measure. The developing environment has more soft "uncertainty" than the developed environment; and "hard" uncertainty in the developing environment is masked by a lack of information/data.

In the foodbanking context the problem structure was often unstable and susceptible to change (e.g. the logistical structure), particularly as it was a new organization and open to change and evolution. It is therefore felt that techniques employed in such a scenario should either be very simplistic (in order to reduce the time cost so that the problem can be re-solved if changes are incurred) or easily adaptable to a changing environment. This also possibly explains why the harder techniques are in some instances more suited to the developed world. These techniques are typically more rigid and therefore suited to a steady environment. The large availability of data in the developed world also allows more complex models to be fitted (which usually require more parameters), whereas the lack of data in the developing environment enforces simplistic modelling and more of an emphasis on problem structuring.

As a result of the differences in goals and uncertainty, detailed techniques developed for First World industry (e.g. around inventory management) could not be directly transferred. Hard techniques were still applicable (e.g. simulation for warehouse size and location), though these were "custom built" according to the given environment. These proved very useful and helped to incorporate relevant expertise in a new environment in a systematic and logical manner to solve problems. much in the same way that OR did in its early stages in World War 2.

7.3.3 Client

Our experience was that buy-in from clients differed according to the techniques employed. For softer techniques, buy-in was predominantly based on their understanding and trust in the technique, as they were actively participating in the work. An example of this was the workshops for the allocation model, where issues centred on the work content. Along these lines it was found that the style of thinking between facilitator and participant was initially an obstacle. The OR style of thinking is generally to attempt to simplify and model reality in order to solve problems. The reality of participants in this case is very practical, social and complex. Participants therefore seemed resistant at first, as in their eyes the reality was too complex to attempt to break up and model. It also took time to convince them that it is better to model approximately, even if it is imperfect, than to not model at all.

Due to the increased level of involvement in the solution development with the softer techniques, it was found that there was an increased understanding of the system and problem within the system when these were used. It is felt that this understanding is an integral part of the solution. An illustration of this was in creating a leadership structure, where an increased understanding was essential in implementing the co-chairs structure.

For the harder techniques, buy-in seemed to centre more on personal trust in the OR practitioner's competence. Examples of this were the warehouse size and location, where the clients had only a very broad idea of the research but were generally happy to accept and implement its conclusions due to a level of personal trust. Sometimes conclusions needed to be substantiated, though this would be through underlying rationale rather than an explanation of the method used.

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Appendix A

Coding

A.1 Warehouse Size

A.1.1 Evaluating storage requirements for Non-perishable product

```
Function week(data As Range) As Variant

'This repeats the exercise a number of times in order to get
'an accurate estimate, and each time stores performance
'measures.
iterations = 100
ReDim results0(iterations)
ReDim results1(iterations)
ReDim results2(iterations)

For k = 1 To iterations

    ''''''''''THIS SIMULATES THE STORAGE VALUES''''''''''''
    weeks = 260

    'This reads in the constants from the spreadhseet
    gammaprob = data(1)
    gammashape = data(2)
    gammascale = data(3)
    normprob = data(6)
    normmean = data(7)
    normsd = data(8)
```

```
    overallmean = data(10)
    outflowfactor = data(11)

    'This keeps track of storage, outflows and inflows each
'week
    ReDim storage1(weeks)
    ReDim Outflow1(weeks)
    ReDim inflow(weeks)

    'This calculates the inflows for step 1:

        'If a random number is less than a certain amount then
'the
'inflow is gamma distributed
        If Rnd() < gammaprob Then inflow(1) = Application.
WorksheetFunction.GammaInv(Rnd(), gammashape, gammascale)
        'Otherwise it is normally distributed
        Else: inflow(1) = Application.WorksheetFunction.
NormInv(Rnd(), normmean, normsd)
        End If

    'This calculates the storage:
        storage1(1) = inflow(1)

    'This calculates the inflows:

        'If the storage is more than the maximum outflow, then
'the
'maximum outflow is used:
        If storage1(1) > overallmean * outflowfactor Then
        Outflow1(1) = overallmean * outflowfactor
        'Otherwise whatever is in storage is used:
        Else: Outflow1(1) = storage1(1)
        End If

    'The same is now calculated but for the subsequent weeks:
    For i = 2 To weeks

        'Inflows:
        If Rnd() < gammaprob Then
```

```
        inflow(i) = Application.WorksheetFunction.GammaInv(
Rnd(), gammashape, gammascale)
        Else: inflow(i) = Application.WorksheetFunction.
NormInv(Rnd(), normmean, normsd)
        End If

        'Storage:
        storage1(i) = inflow(i) + storage1(i - 1) -
Outflow1(i - 1)

        'Outflows:
        If storage1(i) > overallmean * outflowfactor Then
        Outflow1(i) = overallmean * outflowfactor
        Else: Outflow1(i) = storage1(i)
        End If

    Next i

    '''THIS SORTS THE STORAGE VALUES TO CREATE CUT-OFFS'''

    's is created equal to "storage" but is able to be
'changed
    ReDim s(weeks)

    For i = 1 To weeks
        s(i) = storage1(i)
    Next i

    'z is the sorted array
    ReDim z(weeks)

    'each j entry will be the next ranked value in z
    For j = 1 To weeks

        'z takes on the minimum of c
        z(j) = Application.WorksheetFunction.Min(s)

        'c is then looped through in order to find which
'value was put in z.  This value is then changed
'to a big number so that it is not picked up
```

```
'again by z.
        For i = 1 To weeks
        If z(j) = s(i) Then
        s(i) = 1000000
        End If
        Next i

    Next j

    'This gives the 10% upper limit
    results0(k) = z(weeks * 0.9)

    'This gives the 5% upper limit
    results1(k) = z(weeks * 0.95)

    'This gives the 1% upper limit
    results2(k) = z(weeks * 0.99)

Next k

Dim results(5) As Double

results(0) = Application.WorksheetFunction.Average(results0)
results(1) = Application.WorksheetFunction.StDev(results0) /
Sqr(iterations)
results(2) = Application.WorksheetFunction.Average(results1)
results(3) = Application.WorksheetFunction.StDev(results1) /
Sqr(iterations)
results(4) = Application.WorksheetFunction.Average(results2)
results(5) = Application.WorksheetFunction.StDev(results2) /
Sqr(iterations)

week = results

End Function
```

A.1.2 Evaluating performance for differing outflow factors and the decision rule

```
Function week(data As Range) As Variant
```

```
'This repeats the exercise a number of times in order to get an
'accurate estimate, and each time stores performance measures.
iterations = 100
ReDim results0(iterations)
ReDim results1(iterations)
ReDim results2(iterations)
ReDim results3(iterations)
ReDim results4(iterations)
ReDim results5(iterations)
ReDim results6(iterations)
ReDim results7(iterations)

For k = 1 To iterations

    ''''''''''THIS SIMULATES THE STORAGE VALUES''''''''''''
    weeks = 260

    'This reads in the constants from the spreadhseet
    gammaprob = data(1)
    gammashape = data(2)
    gammascale = data(3)
    normprob = data(6)
    normmean = data(7)
    normsd = data(8)
    overallmean = data(10)
    outflowfactor = data(11)
    dailymean = data(13)
    dailysd = data(14)
    totaldailymean = data(15)

    'This keeps track of storage, outflows, inflows and sum of
'squares each week
    ReDim storage1(weeks)
    ReDim storage2(weeks)
    ReDim outflow1(weeks)
    ReDim inflow(weeks)
    ReDim sumofsq1(weeks)
    ReDim sumofsq2(weeks)
```

```
    'This calculates the inflows for step 1:

        'If a random number is less than a certain amount then
'the inflow is gamma distributed
        If Rnd() < gammaprob Then
        inflow(1) = Application.WorksheetFunction.GammaInv(
Rnd(),gammashape, gammascale)
        'Otherwise it is normally distributed
        Else: inflow(1) = Application.WorksheetFunction.
NormInv(Rnd(), normmean, normsd)
        End If

    'This calculates the storage for step 1:
        storage1(1) = inflow(1)
        storage2(1) = inflow(1)

    'This calculates the outflows for step 1:

        'If the storage is more than the maximum outflow, then
'the maximum outflow is used:
        If storage1(1) > overallmean * outflowfactor Then
        outflow1(1) = overallmean * outflowfactor
        'Otherwise whatever is in storage is used:
        Else: outflow1(1) = storage1(1)
        End If

    'This calculates the perishable daily inflows:
        ReDim per(7)
        dummy = 0

        For n = 1 To 7
        per(n) = Application.WorksheetFunction.NormInv(Rnd(),
dailymean, dailysd)

            If per(n) < totaldailymean And storage2(1) >=
totaldailymean - per(n) Then
            outflow2 = totaldailymean - per(n)
            storage2(1) = storage2(1) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2
```

```
            ElseIf per(n) < totaldailymean And storage2(1) <
totaldailymean - per(n) Then
            outflow2 = storage2(1)
            storage2(1) = storage2(1) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2

            Else
            outflow2 = 0
            storage2(1) = storage2(1) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2

            End If

        Next n
    'Squared difference for 2:
    sumofsq2(1) = dummy


    'Squared difference for 1:
        dummy = 0
        For n = 1 To 7
        dummy = dummy + (per(n) + outflow1(1) / 7 -
totaldailymean) ^ 2
        Next n
        sumofsq1(1) = dummy

    'The same is now calculated but for the subsequent weeks:
    For i = 2 To weeks

        'Inflows:
        If Rnd() < gammaprob Then
        inflow(i) = Application.WorksheetFunction.GammaInv(
Rnd(), gammashape, gammascale)
        Else: inflow(i) = Application.WorksheetFunction.
NormInv(Rnd(), normmean, normsd)
        End If
```

```
        'Storage:
        storage1(i) = inflow(i) + storage1(i - 1) -
outflow1(i - 1)
        storage2(i) = inflow(i) + storage2(i - 1)

        'Outflows:
        If storage1(i) > overallmean * outflowfactor Then
        outflow1(i) = overallmean * outflowfactor
        Else: outflow1(i) = storage1(i)
        End If

        'This calculates the perishable daily inflows:
        ReDim per(7)
        dummy = 0

        For n = 1 To 7
        per(n) = Application.WorksheetFunction.NormInv(Rnd(),
dailymean, dailysd)

            If per(n) < totaldailymean And storage2(i) >=
(totaldailymean - per(n)) Then
            outflow2 = totaldailymean - per(n)
            storage2(i) = storage2(i) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2

            ElseIf per(n) < totaldailymean And storage2(i) <
(totaldailymean - per(n)) Then
            outflow2 = storage2(i)
            storage2(i) = storage2(i) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2

            Else
            outflow2 = 0
            storage2(i) = storage2(i) - outflow2
            dummy = dummy + (per(n) + outflow2 -
totaldailymean) ^ 2

            End If
```

```
        Next n
    'Squared difference for 2:
    sumofsq2(i) = dummy


    'Squared difference for 1:
        dummy = 0
        For n = 1 To 7
        dummy = dummy + (per(n) + outflow1(1) / 7 -
totaldailymean) ^ 2
        Next n
        sumofsq1(i) = dummy


    Next i

    '''''THIS SORTS THE STORAGE2 VALUES TO CREATE CUT-OFFS'''''

    's is created equal to "storage" but is able to be changed
    ReDim s2(weeks)

    For i = 1 To weeks
        s2(i) = storage2(i)
    Next i

    'z is the sorted array
    ReDim z2(weeks)

    'each j entry will be the next ranked value in z
    For j = 1 To weeks

        'z takes on the minimum of c
        z2(j) = Application.WorksheetFunction.Min(s2)

        'c is then looped through in order to find which value
        'was put in z.  This value is then changed to a big
'number
        'so that it is not picked up again by z.
        For i = 1 To weeks
```

```
        If z2(j) = s2(i) Then
        s2(i) = 1E+30
        GoTo skip2
        End If
        Next i

skip2:
    Next j

    'This gives the 10% upper limit
    results4(k) = z2(weeks * 0.9)

    'This gives the 5% upper limit
    results5(k) = z2(weeks * 0.95)

    'This gives the 1% upper limit
    results6(k) = z2(weeks * 0.99)

    'This gives the standard deviation:
    results7(k) = Sqr(Application.WorksheetFunction.
Sum(sumofsq2) / (weeks * 7 - 1))

    '''THIS SORTS THE STORAGE1 VALUES TO CREATE CUT-OFFS'''

    's is created equal to "storage" but is able to be changed
    ReDim s(weeks)

    For i = 1 To weeks
        s(i) = storage1(i)
    Next i

    'z is the sorted array
    ReDim z(weeks)

    'each j entry will be the next ranked value in z
    For j = 1 To weeks

        'z takes on the minimum of c
        z(j) = Application.WorksheetFunction.Min(s)
```

```
        'c is then looped through in order to find which value
        'was put in z.  This value is then changed to a big
'number so that it is not picked up again by z.
        For i = 1 To weeks
        If z(j) = s(i) Then
        s(i) = 1000000
        GoTo skip
        End If
        Next i

skip:
    Next j

    'This gives the 10% upper limit
    results0(k) = z(weeks * 0.9)

    'This gives the 5% upper limit
    results1(k) = z(weeks * 0.95)

    'This gives the 1% upper limit
    results2(k) = z(weeks * 0.99)

    'This gives the standard deviation:
    results3(k) = Sqr(Application.WorksheetFunction.
Sum(sumofsq1) / (weeks * 7 - 1))

Next k

Dim results(15) As Double

results(0) = Application.WorksheetFunction.Average(results0)
results(1) = Application.WorksheetFunction.StDev(results0) /
Sqr(iterations)
results(2) = Application.WorksheetFunction.Average(results1)
results(3) = Application.WorksheetFunction.StDev(results1) /
Sqr(iterations)
results(4) = Application.WorksheetFunction.Average(results2)
results(5) = Application.WorksheetFunction.StDev(results2) /
Sqr(iterations)
results(6) = Application.WorksheetFunction.Average(results3)
```

```
results(7) = Application.WorksheetFunction.StDev(results3) /
Sqr(iterations)

results(8) = Application.WorksheetFunction.Average(results4)
results(9) = Application.WorksheetFunction.StDev(results4) /
Sqr(iterations)
results(10) = Application.WorksheetFunction.Average(results5)
results(11) = Application.WorksheetFunction.StDev(results5) /
Sqr(iterations)
results(12) = Application.WorksheetFunction.Average(results6)
results(13) = Application.WorksheetFunction.StDev(results6) /
Sqr(iterations)
results(14) = Application.WorksheetFunction.Average(results7)
results(15) = Application.WorksheetFunction.StDev(results7) /
Sqr(iterations)

week = results

End Function
```


A.2 Warehouse Location

The coding is split into two parts. Firstly, a pseudocode is given for the Clarke-Wright algorithm. Secondly, the actual VBA code for the entire warehouse location algorithm is given.

A.2.1 Pseudocode for Clarke Wright Algorithm

An overview of the algorithm was given in Section 2.4.2. Customers 1 to n which are also nodes 1 to n), referred to in that section, are now represented as regions 1 to n, with the warehouse denoted as node 0. Below is the pseudocode for the algorithm:

1. x and y coordinates were given for each region as well as the number of agencies remaining in each area.
2. Using the x and y coordinates, matrix d was calculated, where du is the Euclidean distance between regions i and j. This was then multiplied by a factor of 1.3 to give the road distance.

3. Using matrix $(1,$ matrix s could be calculated using the formula given in Section 2.4.2: sij $=$ $di()$ doj — dij (distance d_{ij} is here used as a proxy for cost cij between nodes i and j as distance is later converted to financial cost in the original algorithm). The number of possible distinct savings between two regions is z = $n(n - 1)/2$, assuming that $=$ for all i, j and thus that sij sji for all i, j.

4. A number of arrays were then set up that acted as a database, keeping track of necessary information. Four arrays were required:

   (a) Cost

   (b) Load

   (c) Extremel

   (d) Extreme2

   The database could then be viewed as an ((n z) x 4) matrix (reason for having (n z) rows to follow). Each row number would refer to a unique route, therefore giving each row a unique "route id", and would contain information on the cost of the route (road distance in this case), the load of the route (which in this case is the number of agencies), the first region visited (Extremel) and the last region visited (Extreme2). Therefore Cost(i), Load(i), Extremel(i) and Extreme2(i) would all contain information on "route i", i = 1 to $(in \pm 4$ The Load, Extremel and Extreme2 arrays are used to check for the three merger conditions, and the Cost array keeps track of the cost of the route.

   As described in Section 2.4.2, the initial set-up has n routes, each of which has a separate vehicle travelling from the warehouse to a single customer and back. Consequently the first n entries of the database are filled in accordingly. As regions are combined into single routes, their "parents" (or original routes) are set to 0 and the new route is then added. There are z possible savings to cycle through, therefore the procedure will need to be looped z times. If a new route is created (from a merger) on iteration k, it is input into row $n + k$. This explains why the database is of dimension ((n x 4). The database starts with n entries and then cycles through z possible savings, each of which could potentially be added to the database. A more elegant solution could be achieved by replacing one of the "parent- routes with the new route, in which case the database would only need n rows, but the given solution worked well enough in practice time constraints did not permit coding the more elegant solution.

5. The following loop was then used to calculate all the routes:

   For $k = 1$ to z

   - Find max(s) with associated regions i and j
   - Set a = Route(i) and b = Route(j). Regions i and j each belong to a certain route (or row number). Route(i) and Route(j) are used to denote which route regions i and j are a part of. Therefore, for example, region 10 may be part of route 16, in which case i = 10 and a = 16.
   - Check to see if the three conditions (from Section 2.4.2) are satisfied for a possible merger between regions i and j
     -- If all three conditions are passed, then merge regions i and j
     — Else do not merge regions i and j
   - Change sjj to 0

   Next k

Assume now that the code is on iteration k and that regions i and j have been selected from max(sii). The following two sub-sections describe how the three conditions are checked and, if the conditions are satisfied, how the merger occurs.

Checking the three conditions

In order for a merger to occur between i and j the following three criteria need to be satisfied:

(a) The truck capacity cannot be exceeded;

(b) Neither i nor j can be internal to a route; and

(c) Regions i and j cannot be part of the same route.

Every region will always be contained in exactly one route. This results in four "possibilities" for **Route(i)** and **Route(j).** These -possibilities" are given for **Route(i),** but the same is true for **Route(** ***j):***

(a) $i = \mathbf{Extreme1}(i)$ and $i \neq \mathbf{Extreme2}(i)$

(b) $i \neq \mathbf{Extreme1}(i)$ and $i = \mathbf{Extreme2}(i)$

(c) $i = \mathbf{Extreme1}(i)$ and $i = \mathbf{Extreme2}(i)$

(d) $i \neq \mathbf{Extreme1}(i)$ and $i \neq \mathbf{Extreme2}(i)$

As a result the three conditions translate directly into the following:

(a) $\mathbf{Load}(a) + \mathbf{Load}(b) <$ capacity of truck

(b) Neither i nor j can be "possibility" (d) (as they would then be interior to the route)

(c) $a \neq b$

If these three criteria are satisfied, the merger occurs.

Merger

If the three criteria were satisfied, Route(i) = a and Route(j) = b need to be combined. Recall that the code is on iteration k. The new route will then be input On row *(ii* k*)* of the database. In the database, the values of the two "parent" routes are all set to 0 and the values for Cost, Load, Extremel and Extreme2 of the new route need to be calculated. For Cost and Load this results in:

$$\text{Cost}(\text{n } k) = \text{Cost}(a)\ \text{Cost}(b)\ -$$
$$\text{Load}(\text{n } k) = \text{Load}(a)\ \text{Load}(b)$$

Both i and j can be part of three of the "possibilities" as defined above, assuming "possibility" 4 cannot hold as the merge is feasible. This results in 9 potential combinations between the "possibilities" of i and j. The 9 combinations of "possibilities" are listed in Table Al, along with what the new values for Extremel and Extreme2 will be for each. At this point the new route has been calculated and the old routes have been deleted. The loop can then continue to the next iteration.

6. Once the loop has completed all iterations, the set of routes in the database will be the final set of routes, and by simply summing the Cost array, one can calculate the total cost (or distance in this case) of these routes.

Table A.1: The combinations of "possibilities" and the resultant **Extreme1** and **Extreme2** values

Possibility of i	**Possibility of** j	**Extreme1**$(n+k)$	**Extreme2**$(n+k)$
a	a	**extreme2**(a)	**extreme2**(b)
a	b	**extreme1**(b)	**extreme2**(a)
a	c	**extreme1**(b)	**extreme2**(a)
b	a	**extreme1**(a)	**extreme2**(b)
b	b	**extreme1**(a)	**extreme1**(b)
b	c	**extreme1**(a)	**extreme2**(b)
c	a	**extreme1**(a)	**extreme2**(b)
c	b	**extreme1**(b)	**extreme2**(a)
c	c	**extreme1**(a)	**extreme2**(b)

A.2.2 VBA Code

```
'*****THIS CODE CALCULATES THE TOTAL TRANSPORTATION COST*****

Function routing2(warehouse As Range, assumptions As Range,
xcoord As Range, ycoord As Range, radius As Range,
number_agencies As Range) As Variant

'THE TRANSPOARTATION COST FOR WHOLE TRIPS IS FIRST CALCULATED:

'"warehouse" is the warehouse coordinates; "assumptions" is
'the list of assumptions; "xarea" and "yarea" are the
'coordinates of the areas; "radius" is the radii of the areas;
'"number_agencies" is the number of beneficiaries/agencies in
'each area.

'Where results will be stored:
Dim results(1) As Double

'Calculate the number of areas (n):
n = Application.WorksheetFunction.Count(xcoord)
```

```
'This is the coordinates of the warehouse.  The coords of the
'areas are put in new variables "xarea" and "yarea" so that
'they can be changed later on.
warehousex = warehouse(1)
warehousey = warehouse(2)
ReDim xarea(n)
ReDim yarea(n)
For i = 1 To n
xarea(i) = xcoord(i)
yarea(i) = ycoord(i)
Next i

'This is the list of assumptions and decision variables other
'than the warehouse coords.
pick_up_radius = assumptions(1)
deliveries_per_wk = assumptions(2)
num_days_of_operation = assumptions(3)
distribution_per_wk = assumptions(7)
total_agencies = assumptions(8)
load_of_truck = assumptions(10)
petrol_price = assumptions(11)
fuel_con = assumptions(12)
travel_time = assumptions(14)
time_at_agency = assumptions(15)
time_on_road = assumptions(16)
time_to_load_truck = assumptions(17)
prop_covered = assumptions(19)
air_to_road = assumptions(20)

'''''FOR EACH AREA THE FOLLOWING NEEDS TO BE CALCULATED:'''''
ReDim distance(n)
ReDim proportion(n)
ReDim dist_bet_agencies(n)
ReDim deliver_dist(n)
ReDim pick_up_dist(n)
ReDim num_deliver(n)
ReDim num_pick_up(n)
ReDim dist_per_trip(n)
ReDim num_trips(n)
ReDim total_trip_dist(n)
```

```
ReDim leftover(n)
ReDim total_inbetween_dist(n)
ReDim agency_cost(n)

For i = 1 To n

'Calculate the distance from the warehouse to the midpoint of
'areas.
distance(i) = air_to_road * (Sqr((xarea(i) - warehousex) ^ 2
+ (yarea(i) - warehousey) ^ 2))

'Calculate distance between agencies in same area
dist_bet_agencies(i) = air_to_road * 2 * radius(i) *
Sqr(0.75 * prop_covered / number_agencies(i))

Next i

'These constants can now be calculated and need to be before
'the subsequent arrays can be.
volume_per_agency = distribution_per_wk /
(total_agencies * deliveries_per_wk)
Count = 0
For i = 1 To n
Count = Count + number_agencies(i) * dist_bet_agencies(i)
Next i

average_dist_between_suppliers = Count / total_agencies
average_distance = Application.WorksheetFunction.
Average(distance)
n_from_time = (travel_time * average_dist_between_suppliers +
time_on_road - time_to_load_truck - 2 * average_distance *
travel_time) / (time_at_agency +
average_dist_between_suppliers * travel_time)
agencies_per_trip = Application.WorksheetFunction.
Min(load_of_truck / volume_per_agency, n_from_time)
agencies_per_trip = load_of_truck / volume_per_agency

For i = 1 To n
    'Calculate proportion agencies that pick up for each area
    'as well as distance for pick up and delivery:
```

```
x1 = pick_up_radius
y1 = radius(i)
z1 = distance(i)
If x1 = 0 Then
proportion(i) = 0
deliver_dist(i) = z1
pick_up_dist(i) = 0
ElseIf y1 > z1 + x1 Then
proportion(i) = (x1 ^ 2) / (y1 ^ 2)
deliver_dist(i) = Application.WorksheetFunction.
Max(dist_bet_agencies, x1)
pick_up_dist(i) = 0.92 * y1
ElseIf y1 + z1 < x1 Then
proportion(i) = 1
deliver_dist(i) = 1
pick_up_dist(i) = z1
ElseIf z1 - y1 > x1 Then
proportion(i) = 0
deliver_dist(i) = z1
pick_up_dist(i) = z1
Else
prop1 = (y1 ^ 2) * Application.WorksheetFunction.
Acos((z1 ^ 2 + y1 ^ 2 - x1 ^ 2) / (2 * z1 * y1))
prop2 = (x1 ^ 2) * Application.WorksheetFunction.
Acos((z1 ^ 2 + x1 ^ 2 - y1 ^ 2) / (2 * z1 * x1))
prop3 = 0.5 * Sqr((-z1 + y1 + x1) * (z1 + y1 - x1) *
(z1 - y1 + x1) * (z1 + y1 + x1))
prop4 = 3.1416 * (y1 ^ 2)
proportion(i) = (prop1 + prop2 - prop3) / prop4
deliver_dist(i) = (x1 + y1 + z1) / 2
pick_up_dist(i) = (x1 - y1 + z1) / 2
'xarea and yarea are now changed to the drop-off
'coordinates. xarea and yarea are only used again in
'the Clarke Wright algorithm therefore they can
'simple be changed now instead of creating a new
'variable.
xa = warehousex + (x1 / z1) * (xarea(i) -
warehousex)
ya = warehousey + (x1 / z1) * (yarea(i) -
warehousey)
```

```
    xb = warehousex + ((y1 + z1) / x1) * (xarea(i) -
    warehousex)
    yb = warehousey + ((y1 + z1) / x1) * (yarea(i) -
    warehousey)
    '(xc, yc, xp and yp are left out)
    xarea(i) = (xa + xb) / 2
    yarea(i) = (ya + yb) / 2
    End If

    'Calculate # agencies that deliver and pick up
    num_deliver(i) = (1 - proportion(i)) * number_agencies(i)
    num_pick_up(i) = proportion(i) * number_agencies(i)

    'Calculate the total distance per trip
    dist_per_trip(i) = deliver_dist(i) * 2 +
    dist_bet_agencies(i) * (agencies_per_trip - 1)

    'Calculate # trips to an area
    num_trips(i) = Application.WorksheetFunction.
    RoundDown(num_deliver(i) / agencies_per_trip, 0)

    'Calculate distance travelled for all trips to an area
    total_trip_dist(i) = dist_per_trip(i) * num_trips(i)

    'Calculate left over agencies in each area after the
    '"full" trips.
    leftover(i) = Application.WorksheetFunction.
    Round(num_deliver(i) - agencies_per_trip * num_trips(i),0)

    'Calculate total travel distance inbetween agencies
    total_inbetween_dist(i) = Application.WorksheetFunction.
    Max((leftover(i) - 1), 0) * dist_bet_agencies(i)

    'Calculate agency cost per area
    agency_cost(i) = num_pick_up(i) * pick_up_dist(i) * 2 /
    fuel_con * petrol_price

Next i

''THE TRANSPORTATION COST FROM THE CLARKEWRIGHT DISTANCE IS
```

```
''NOW CALCULATED:''

''''SUMMARY OF CODE:''''
'Calculate x and y coords and leftover values
'Calculate distance matrix
'Calculate savings matrix
'set up database R
'For k = 1 To z
    'find max(s) with associated areas i and j
    'do 3 checks on "load", "i" and "j" in database.
    'if good - merge; if not - don't
    'change s(i, j) to 0
'Next i

'**********************************************************
'the warehouse and area coordintes are input seperately for
'more flexibility on the spreadsheet but will be combined
'in a single vector for ease of calculation.

'ntot gives the total number of areas + the warehouse. N
'gives the number of areas with left overs + the warehouse.
ntot = Application.WorksheetFunction.Count(xarea) + 1
n = 1
For i = 1 To ntot - 1
If leftover(i) > 0 Then
n = n + 1
End If
Next i

'The new x, y and leftover arrays are calculated. x(1) and
'y(1) are the warehouse coordinates and areas where there
'is no "left overs" are left out:
ReDim x(n)
ReDim y(n)
ReDim leftnew(n)
x(1) = warehouse(1)
y(1) = warehouse(2)

'This looks through the "leftover" array to see where there
'are left overs. Where there are, the area coordinates and
```

```
'left over values are added to the x, y and "leftnew" arrays.
Count = 1
For i = 1 To ntot - 1
If leftover(i) > 0 Then
Count = Count + 1
x(Count) = xarea(i)
y(Count) = yarea(i)
leftnew(Count) = leftover(i)
End If
Next i

'Calculating the distance matrix. The diagonal elements
'(distance from an area to itself) are not needed.
'd(1,3) = distance between warehouse and area 2. d(3,1) = 0.
ReDim d(n - 1, n)
For i = 1 To n - 1
For j = i + 1 To n
d(i, j) = Sqr((x(i) - x(j)) ^ 2 + (y(i) - y(j)) ^ 2)
Next j
Next i

'Calculate savings S: (goes to n - 1 as only need savings
'between areas and not warehouse).
's(1,5) = saving between area 1 and area 5.
ReDim s(n - 1, n - 1)
For i = 1 To n - 1
'goes from j = i + 1 as saving to same area is 0.
For j = i + 1 To n - 1
s(i, j) = d(1, i + 1) + d(1, j + 1) - d(i + 1, j + 1)
Next j
Next i

'******SETTING UP R:******
'z is the number of "savings" elements to go through in the
'matrix:
z = (n - 1) * (n - 2) / 2
'Defining the data headings:
ReDim cost(z + n)
ReDim Load(z + n)
ReDim extreme1(z + n)
```

```
ReDim extreme2(z + n)

'Start-off values:
For i = 1 To n - 1
cost(i) = 2 * d(1, i + 1)
Load(i) = leftover(i)
extreme1(i) = i
extreme2(i) = i
Next i

'This loops through the data structure:
For k = 1 To z
maxs = 0
a = 0
b = 0
    'This finds max(s) with associated a and b
    For i = 1 To n - 1
        For j = i + 1 To n - 1
            If s(i, j) > maxs Then
            maxs = s(i, j)
            a = i
            b = j
            End If
        Next j
    Next i

'If all the remaining s(i,j)'s are 0, a and b will be zero and
'the "looping" will be done.
If a = 0 Or b = 0 Then
GoTo ending
End If

'This sees what option a and b fall under and in which route
'this is. (a and b can never be in more than one route
'therefore don't need to worry about "over-writing" previous
'values.)
optiona = 0
optionb = 0
routea = 0
routeb = 0
```

```
i = 0

Do
i = i + 1

    If a = extreme1(i) Then
    optiona = 1
    routea = i
    ElseIf b = extreme1(i) Then
    optionb = 1
    routeb = i
    End If

    If a = extreme2(i) Then
    optiona = 2
    routea = i
    ElseIf b = extreme2(i) Then
    optionb = 2
    routeb = i
    End If

    If a = extreme1(i) And a = extreme2(i) Then
    optiona = 3
    routea = i
    ElseIf b = extreme1(i) And b = extreme2(i) Then
    optionb = 3
    routeb = i
    End If

Loop Until (optiona > 0 And optionb > 0) Or (i = z + n)

'Check load not exceeded, Check not interior, check not in
'same route.
infeasible = 0
If (Load(routea) + Load(routeb) > agencies_per_trip) Or
optiona = 0 Or optionb = 0 Or routea = routeb Then
infeasible = 1
End If

'if the merge is feasible then the merger is done: (There are
```

```
'9 possible combinations of options for a and b)
If infeasible = 0 Then
'The new load and cost values are calculated"
cost(n - 1 + k) = cost(routea) + cost(routeb) - s(a, b)
Load(n - 1 + k) = Load(routea) + Load(routeb)

'The 9 combinations of options:
    If optiona = 1 And optionb = 1 Then
    extreme1(n - 1 + k) = extreme2(routea)
    extreme2(n - 1 + k) = extreme2(routeb)
    End If

    If optiona = 1 And optionb = 2 Then
    extreme1(n - 1 + k) = extreme1(routeb)
    extreme2(n - 1 + k) = extreme2(routea)
    End If

    If optiona = 1 And optionb = 3 Then
    extreme1(n - 1 + k) = extreme1(routeb)
    extreme2(n - 1 + k) = extreme2(routea)
    End If

    If optiona = 2 And optionb = 1 Then
    extreme1(n - 1 + k) = extreme1(routea)
    extreme2(n - 1 + k) = extreme2(routeb)
    End If

    If optiona = 2 And optionb = 2 Then
    extreme1(n - 1 + k) = extreme1(routea)
    extreme2(n - 1 + k) = extreme1(routeb)
    End If

    If optiona = 2 And optionb = 3 Then
    extreme1(n - 1 + k) = extreme1(routea)
    extreme2(n - 1 + k) = extreme2(routeb)
    End If

    If optiona = 3 And optionb = 1 Then
    extreme1(n - 1 + k) = extreme1(routea)
    extreme2(n - 1 + k) = extreme2(routeb)
```

```
    End If

    If optiona = 3 And optionb = 2 Then
    extreme1(n - 1 + k) = extreme1(routeb)
    extreme2(n - 1 + k) = extreme2(routea)
    End If

    If optiona = 3 And optionb = 3 Then
    extreme1(n - 1 + k) = extreme1(routea)
    extreme2(n - 1 + k) = extreme2(routeb)
    End If

'This sets the "parents" of the merger to 0.
cost(routea) = 0
Load(routea) = 0
extreme1(routea) = 0
extreme2(routea) = 0

cost(routeb) = 0
Load(routeb) = 0
extreme1(routeb) = 0
extreme2(routeb) = 0
End If

'The savings of the original is now set to 0 so that in the
'following loop it is not revisited.
s(a, b) = 0

Next k

ending:

'When new costs are calculated the old ones are set to 0 so
'that by then simply summing the cost array the overall cost
'is given.

clarke = air_to_road * Application.WorksheetFunction.Sum(cost)

distance_travelled = deliveries_per_wk *
(clarke + Application.WorksheetFunction.Sum(total_trip_dist) +
```

```
Application.WorksheetFunction.Sum(total_inbetween_dist))

'Results(0) gives the cost to FBCT
results(0) = distance_travelled / fuel_con * petrol_price
'Results(1) gives the cost to agencies
results(1) = Application.WorksheetFunction.Sum(agency_cost)

routing2 = results

End Function
```